An Analysis of the Remediation Systems on the Contaminant Plume at the Plainville Landfill

by

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ABSTRACT

The Plainville landfill, located in Plainville, Massachusetts, has been the subject of study by several groups in recent years. A contaminant plume, exiting from the southwest corner of the landfill, is contaminating the groundwater downgradient and may affect drinking water wells located there. A two-phase remediation scheme, consisting of an interim overburden air sparging system and a final proposed pump and treat and air sparging system, has been proposed to mitigate the groundwater contaminant plume. This thesis assesses these remediation systems to determine their ability to remediate the contaminants in the groundwater plume.

The interim and final proposed air sparging systems were analyzed using existing quarterly reports and a literature review. A MODFLOW groundwater flow model was used to analyze the pump and treat system. These analyses were then compared to the model utilized to design the remediation scheme.

Several discrepancies in the design of the remediation scheme were noted as a result of this analysis. First, the presence of till lenses throughout the remediation zone was not addressed. Also, the extraction of water from the competent bedrock layer appears counterproductive. In addition, the air sparging system was not field tested to ascertain the flow pattern in the subsurface. Finally, the installation of the bedrock air sparging wells appears redundant. These discrepancies, however, will only decrease the projected efficiency of the proposed remediation schemes and increase clean up time.

Consequently, the results of this study seem to indicate that the proposed remediation scheme is adequately designed.

Thesis Supervisor: Professor Patricia Culligan
Title: Associate Professor of Civil and Environmental Engineering

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1. INTRODUCTION

The Plainville landfill is located in Plainville Massachusetts, approximately 50 miles southwest of Boston, Figure 1. It is the largest landfill in the state of Massachusetts and was in operation for twenty-three years, from 1975 until its capping in 1998. In the early 1980's a groundwater contamination plume, which emanates from the southwest corner of the landfill, was discovered and has since been extensively monitored. Approximately 80,000 people derive their drinking water from the aquifer system underlying the Plainville landfill. Consequently, mitigation of the groundwater plume is essential. A remediation scheme designed in two parts, an interim system and a final permanent system, has been proposed for the Plainville Landfill site. The interim system consists of overburden air sparging wells which have already been installed and will operate in conjunction with the permanent system once approval of the system has been obtained. The final system consists of the interim system with the addition of bedrock air sparging wells and pump and treat wells. This thesis concerns an assessment of the interim and proposed remediation schemes at the Plainville landfill. A description of the landfill, the contamination plume and the groundwater flow model used to depict this area is presented below to better understand the dynamics that will affect the remediation system.

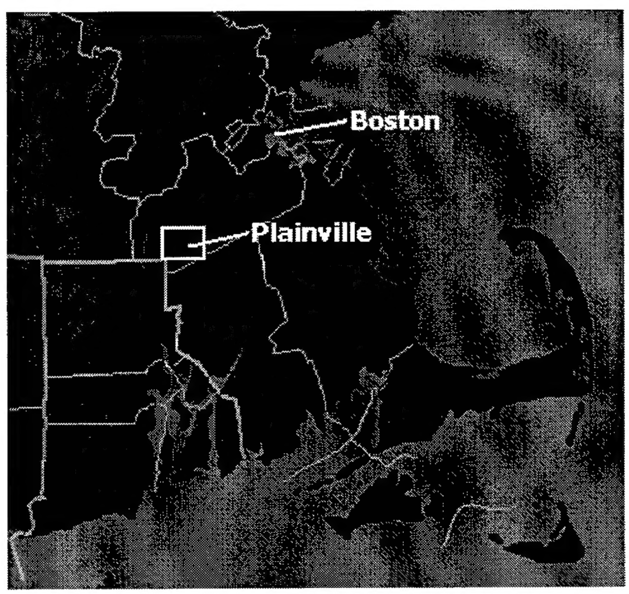

FIGURE 1 PLAINVILLE, MASSACHUSETTS

1.1 PLAINVILLE LANDFILL

Landfills have accepted and continue to accept municipal, industrial and sometimes hazardous wastes. Only during the last twenty years have Americans begun to realize that while landfills consolidate and remove waste from the public view, they may also be a source of hidden danger to the surrounding water and air supplies. Landfills throughout

the country have been leaking contaminants into their surrounding water and air. The Plainville Landfill is no exception.

The Plainville landfill covers approximately 139 acres in Plainville, 47 acres in Wrentham and 1 acre in Foxborough, Figure 2. The actual landfill footprint occupies approximately 92 acres in Plainville. The remaining acreage consists of support buildings, sedimentation ponds and an old quarry. The landfill is bordered by Interstate 495 to the south. Rabbit Hill Pond and Stream border the landfill to the west. To the North lie cranberry bogs; on the east is a private campground and woodlands in Foxborough. Lake Mirimichi lies southwest of the landfill.

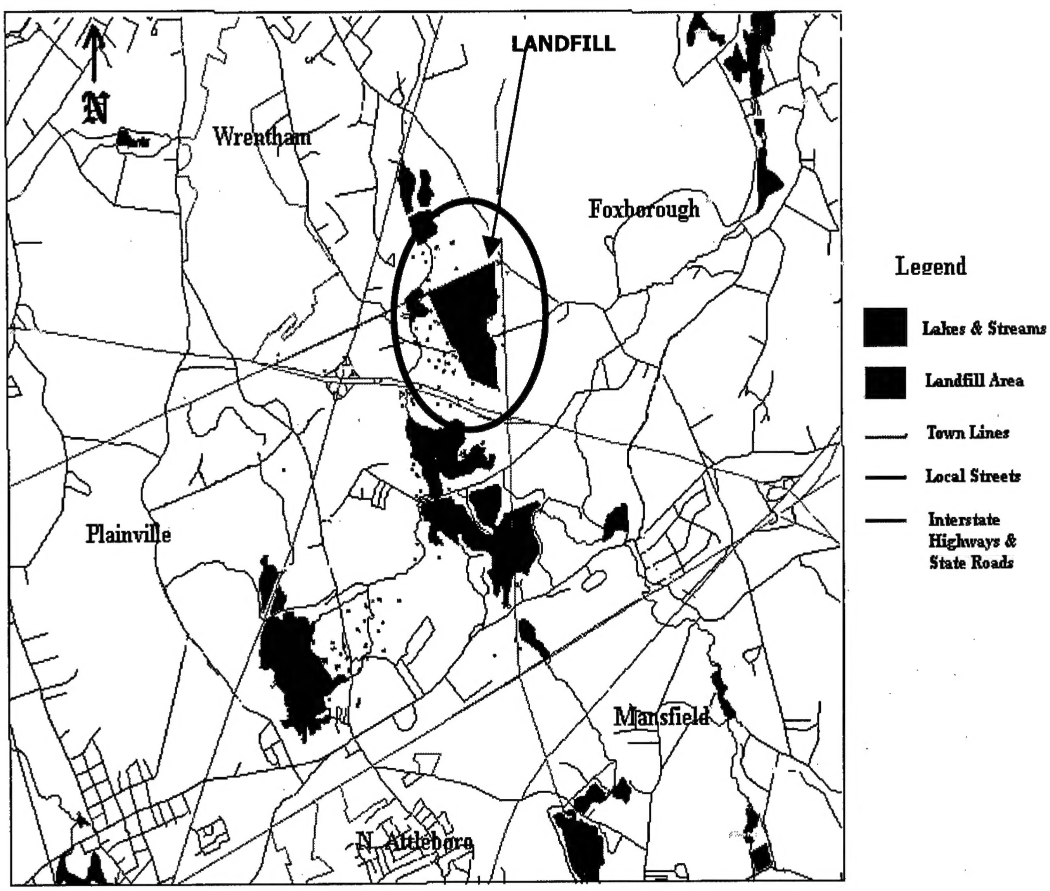

FIGURE 2 PLAINVILLE LANDFILL

The Plainville Landfill ceased accepting wastes on April 1, 1998. Table 1 indicates the amounts and types of waste accepted at the landfill. Most of these wastes are municipal solid wastes. This means that the waste consists primarily of paper, yard, food, plastic, glass, metal and other wastes. Most of these wastes decompose, producing gas. It is primarily the metal and other wastes that concern people. Contaminants such as 1,4-dichlorobenzene, vinyl chloride and other potentially dangerous contaminants have

been found in the groundwater contaminant plume emanating from the Plainville landfill (Chen, 1999).

TABLE 1 WASTE DISPOSED IN PLAINVILLE LANDFILL

Table 1		
Waste Disposal		
May 1993 - April 1994		
Material	Non-MSW & non-Combustibles (tons)	MSW (tons)
Ash	46643	----
Soil/Grit	29462	----
Industrial Residues	16853	----
C & D	9761	----
MSW from Municipal Contract	----	*122284
MSW from Brokers	----	*14584
Waste from Laidlaw Collection/Hauling Divisions	51819	72582
MSW from Other Collection/Hauling Companies	----	*190746
Incinerator By-Pass Waste	----	36983
MSW from Private Generators	----	*754
Total	154538	437933
Percentage of Total	26.10%	73.90%
*No effort has been made to separate non-combustibles from these categories.		
Source: DeFeo, Wait & Pare 1994		

Another source of concern at landfills, including the Plainville site, is leachate. Presently, leachate at the Plainville Landfill is collected and disposed of off-site. Figure 3 shows the amounts of leachate collected from January 1992 until January 1999. These leachate samples are tested for various compounds. Table 2 summarizes some of the substances detected in leachate samples, leachate composite samples, and leachate collection tanks at the landfill. A number of these compounds also exist in the groundwater plume. Notice also that a strong correlation between precipitation and leachate does not exist. This may indicate that the amount of leachate produced may be controlled by another source, such as groundwater infiltration (Chen, 1999). For a more complete analysis of the Plainville landfill, and its role as the source of the contaminant plume, see Chen, 1999.

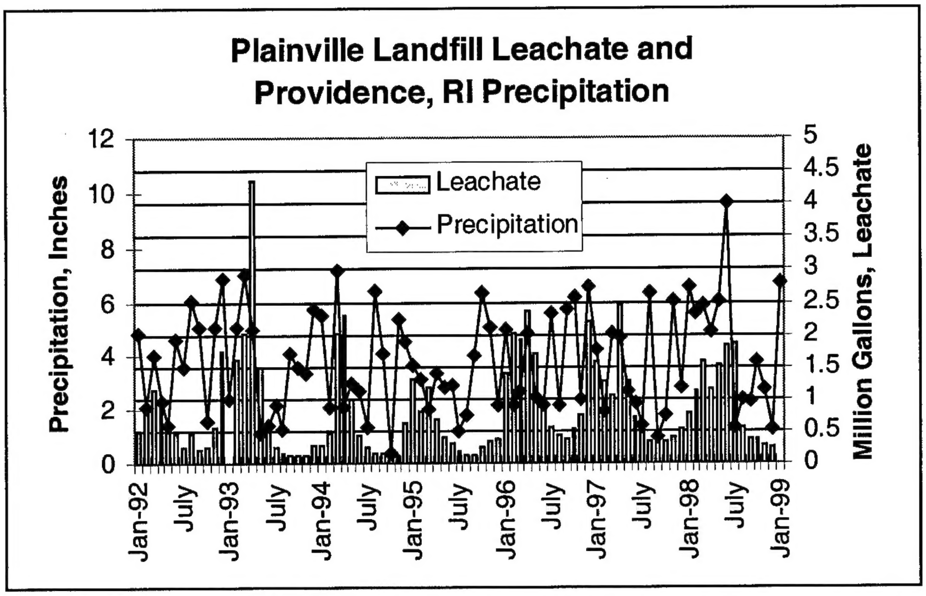

FIGURE 3 LEACHATE AND PRECIPITATION

TABLE 2 SUBSTANCES IN LEACHATE

Analytical Summary: Plainville Sanitary Landfill Substances Reported by GAI as Detected in Leachate Samples, Leachate Composite Samples, and Leachate Collection Tanks From 26 June 1981 to 1990 (concluded)		
1,1-dichloroethane	Benzene	Iron
1,1-dichloroethylene	Chlorobenzene	Lead
1,2-dichloroethane	Chloroform	Manganese
1,2-dichloropropane	Chromium	Methylene Chloride
2-butanone	Cyanide	Tetrachloroethylene
4-methylphenol	Diethylphthalate	Toluene
Acetone	Ethylbenzene	Zinc
Source: Weston 1997		

1.2 PHYSICAL CHARACTERISTICS

Plainville, Massachusetts is located within the Taunton River Watershed. The regional topography in the vicinity of Plainville is characterized by numerous north to south trending buried glacial outwash valleys that are underlain by bedrock, Figure 4. These outwash valleys constitute highly productive aquifers that provide groundwater resources in the region. The elevations in this area range from 450 feet above sea level, at the top of the landfill, to approximately 125 feet above sea level in the outwash valley.

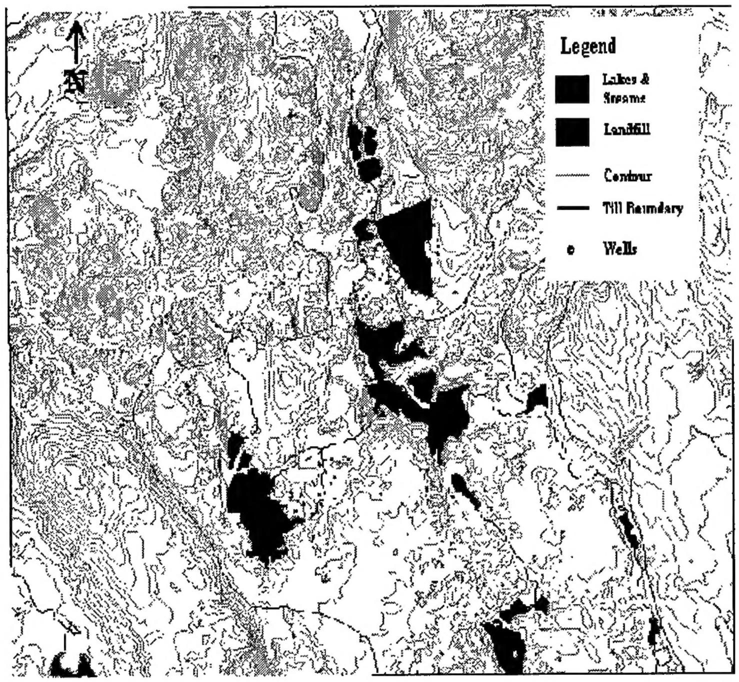

FIGURE 4 GLACIAL OUTWASH VALLEY

Figure 5 illustrates the layers that are present in this glacial outwash valley. The valley consists of glacial outwash that overlies fractured bedrock beginning north of the cranberry bogs, and trending southward from Rabbit Hill Pond towards Lake Mirimichi.

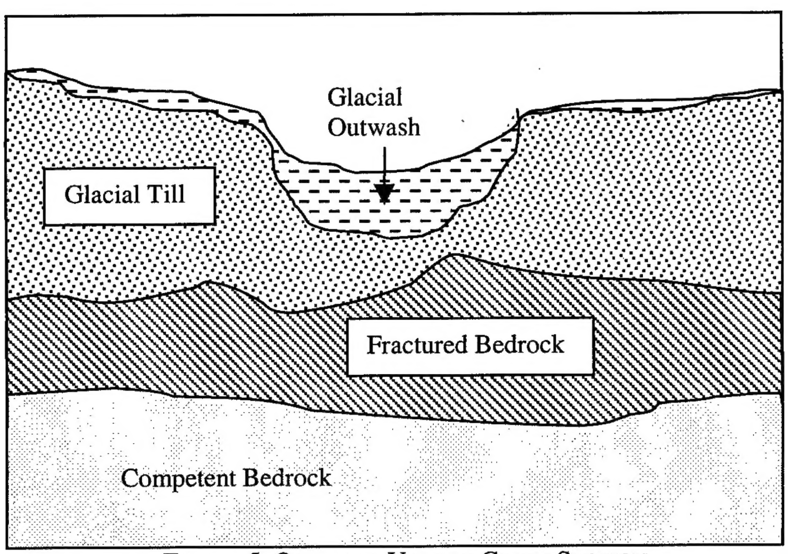

FIGURE 5 OUTWASH VALLEY CROSS SECTION

The glacial outwash consists of fine to coarse sand, some gravel, and little to trace amounts of silt and clay. These outwash deposits increase from as little as eight feet thick to approximately fifty feet thick in the vicinity of Lake Mirimichi. The outwash

conductivity ranges from 150 ft/d to 290 ft/d (Eckenfelder, 1998). The bedrock, which underlies the outwash valley, consists primarily of Dedham Granite with a small area to the east of the landfill underlain by Wamsutta Formation sandstone and conglomerate. (Eckenfelder, 1995). Approximately the top ten feet of the bedrock is fractured and provides groundwater resources to the Plainville area. The hydraulic conductivity within the fractured bedrock ranges from virtually no flow at .00003 ft/d, to 148 ft/d (Eckenfelder, 1998). Glacial till borders the outwash valley on both the west and east. The glacial till is virtually nonconductive, (hydraulic conductivity ranges from 3.1 ft/d to 45 ft/d), and consequently fences in this valley channeling the groundwater flow through the outwash layer (Eckenfelder, 1998). There are also several lenses of relatively coarse-grained glacial till within and beneath the glacial outwash. Boring logs indicate that several lenses of till ranging from 1.5 feet to approximately 10 feet thick are located southwest of the landfill in the vicinity of the groundwater contaminant plume (Eckenfleder, 1998).

A single groundwater flow system underlies the Plainville outwash valley. The aquifer system is unconfined and is recharged from precipitation, at a rate of approximately 21 inches annually. Groundwater flow is generally northeast to southwest along the valley within both the outwash and fractured bedrock layers, which are hydraulically connected. Eckenfelder, after analyzing the groundwater data collected in 1994, concluded that groundwater levels at the landfill property have been observed to fluctuate in response to variations in the rate of precipitation. The overburden wells located in the outwash valley recorded the smallest groundwater level fluctuations in response to rainfall. The bedrock wells along the eastern edge of the landfill recorded the largest groundwater level fluctuations.

2. Groundwater Plume

The groundwater quality in the neighborhood of the landfill has been evaluated using data collected from ongoing groundwater monitoring and the Comprehensive Site Assessment (CSA). Originally, the water samples were tested for alkalinity, ammonia as nitrogen, chemical oxygen demand (COD), chloride, iron, lead, manganese, PH, nitrate and nitrite as nitrogen, specific conductance, sulfate, temperature, total dissolved solids (TSS), zinc, and kjeldahl nitrogen. In the early 1980's these tests were expanded to include testing the groundwater for volatile organic carbons (VOCs), arsenic, cadmium, chromium, mercury, dissolved oxygen, methane, and unknown organics.

2.1 Constituents

Since 1982, eight VOCs have been detected in wells surrounding the landfill on a regular basis. These VOCs are 1-1 dichloroethane, 1-2 dichloroethane, 1-2 dichloropropane, 1-4 dichlorobenzene, benzene, chlorobenzene, chloroethane, and trans 1,2 dichloroethane. The concentrations of these VOCs ranged from 5-8 parts per billion and were found in the wells located downgradient of the landfill. Although these contaminants have been detected in the groundwater plume throughout the 1980s, they have only appeared infrequently and sporadically in the 1990s quarterly reports. Only two contaminants have consistently exceed the Massachusett's Maximum Contaminant Level's (MMCL) of 2 ug/L and 5 ug/L, respectively, within the overburden and bedrock

water bearing zones during the 1990s. These contaminants are vinyl chloride and 1,4-dichlorobenzene (Eckenfelder, 1998).

Vinyl Chloride (C_2H_3Cl) is a byproduct of the degradation of trichloroethylene. Vinyl Chloride also results from the breakdown of other substances, such as trichloroethane, and tetrachloroethylene. Vinyl Chloride's Octanol-Water partitioning coefficient suggests that it does not readily sorb onto soil. However, its Henry's Law constant suggests that it is volatile. These two factors indicate that vinyl chloride will respond well to air sparging. Vinyl Chloride is known to be a carcinogen as determined by the Department of Health and Human Services (DHHS).

1,4 dichlorobenzene, also known as p-DCB or para-DCB, is a chemical used to control moth, molds and mildew, and to deodorize restrooms and waste containers. It is not easily broken down by soil organisms. It's lower Henry's Law constant suggests that 1,4-dichlorobenzene will not respond as well to air sparging. The DHHS has determined that 1,4 Dichlorobenzene may reasonably be anticipated to be a carcinogen.

Table 3 below is a summary of the chemical properties for vinyl chloride and 1,4 dichlorobenzene.

TABLE 3: SUMMARY OF PROPERTIES

CHEMICAL PROPERTY	**Vinyl Chloride (C_2H_3Cl)**	**1,4 Dichlorobenzene ($C_6H_4Cl_2$)**
Molecular Weight (g/mol)	62.5	147
Melting Point (°C)	-153.8	53.1
Boiling Point (°C)	-13.4	174
Density (g/cm^3)	0.91	1.24
Solubility (mol/l)	0.04467	0.000776
Vapor Pressure (atm)	3.89	0.000912
Henry's Const. (L atm/mol)	22.38	2.24
Log K_{ow} (Octanol-Water Partitioning Coeff in mol/l of octanol per mol/l of water)	0.6	3.38

2.2 EXTENT

Appendix A illustrates the 1,4-dichlorobenzene's groundwater contamination plume in the outwash layer for 1997 and 1998. This contaminant was chosen to illustrate the plume and its concentrations because; one, it has most consistently been present in the groundwater and two, it is representative of the vinyl chloride contaminant that also exists in the groundwater plume. The quarterly reports indicate that the concentrations have been increasing until 1994. From 1994 through 1996 the concentrations of 1,4-

dichlorobenzene in wells MW-9R and CD-5 have ranged from 35 μg/L to 43 μg/L. These two wells are located along the highest gradient of the contamination plume and should therefore indicate the highest concentrations in the plume. In 1997, these concentrations declined slightly to the range of 30 μg/L – 33 μg/L. Following the capping of the final cell in 1998, the concentrations of 1,4-dichlorobenzene decreased to the range of 19 μg/L – 21 μg/L. The concentrations of 1,4-dichlorobenzene in the fractured bedrock layer are slightly less than those seen in the outwash layer.

3. GROUNDWATER MODELING

This chapter describes the development of a computer groundwater model using the USGS Modular Finite-Difference Ground-Water Flow Model (MODFLOW) (McDonald and Harbaugh, 1988). This method of analysis was chosen so that quantitative groundwater predictions could be made to aid in the analysis of the remediation scheme at the Plainville landfill. Three other groundwater models have been developed previously for portions of the area of concern. One of the models was developed by Eckenfelder Inc. (1998), one by Dufresne-Henry Inc. (1997), and another by Whitman and Howard (1996). These models were reviewed in detail during the development and construction of the model documented here.

3.1 MODEL DOCUMENTATION

As stated, the purpose of this model was to provide a tool for the study of the remediation system design. The model was used to analyze the radiuses of influence of the extraction and reinjection wells, the capture zone of the extraction wells, and the effect of the final proposed remediation system of the groundwater flow within Plainville landfill area.

3.1.1 CONCEPTUAL MODEL

The model area embodies typical New England geology. The stratified-drift aquifer consists of outwash that has been deposited by glacial meltwaters when glaciers retreated from New England (USGS Water-Supply Paper 2275). These depositions created small, permeable valley-filled aquifers in most of Massachusetts. Specific geologic details of this study's area of concern are provided in Chapter 2.

3.1.2 DATA COLLECTION

In addition to visiting the site, data was gathered from previous studies performed in the area. These data included quarterly reports on chemicals detected in observation wells and ground and surface water elevation measurements, borehole data providing information about the site geology, previous studies done by various consulting companies, and background information on the history of the site. USGS maps of the area were also utilized (USGS 1973, USGS 1987).

3.1.3 Model Description

The USGS MODFLOW, an industry standard for groundwater flow and contaminant transport modeling, was used in conjunction with the user-friendly interface developed by Waterloo Hydrogeologic, Inc. The model determines the distribution of hydraulic head and groundwater flow field over time and space.

MODFLOW is described by its authors as a modular computer program for three-dimensional groundwater flow modeling (McDonald, 1988). The code is structured into independent subprograms or modules. One or more modules together make a "package". These packages address specific aspects of the groundwater system. The MODFLOW packages used for this thesis include: the basic package which establishes basic model structure and computer code bookkeeping and output instructions; the block-centered flow package which establishes geometry and hydraulic properties of model grid; the river package which represents rivers underlain by variable permeability bottoms; the recharge package which specifies the rate of rainfall recharge into the surface of the modeled area; the well package which represents pumping, injection or observation wells; and the preconditioned Conjugate-Gradient Package (PCG2) which solves simultaneous equations produced by the model using a two tier approach. The code provides computational options. MODFLOW can be used for steady state or transient simulations; for this thesis, the model was run in steady-state mode to evaluate long-term average behavior of the groundwater system. In vertical geometry, MODFLOW allows representations as three-dimensional, quasi-three-dimensional, or two-dimensional. This thesis utilized the three-dimensional capability.

3.1.4 Model Development

In order to transform the conceptual model into the three-dimensional numerical model input for the MODFLOW computer program, the horizontal area had to be subdivided into a grid of computational elements. The underlying geology was then represented and the boundary conditions specified. Once these elements were established the physical properties had to be assigned to the model cells.

3.1.4.1 Horizontal Model Area

The model area is shown in Figure 6. Natural boundaries were chosen to define the model. To the east and west, low conductivity till deposits were delineated by no-flow boundaries. The outline of this was determined from a USGS map (USGS 1973) and a USGS topographic map of the area (USGS 1987). The northern boundary and southern boundaries were set at a sufficient distance so that the heads specified at these edges would not affect any evaluation in this study.

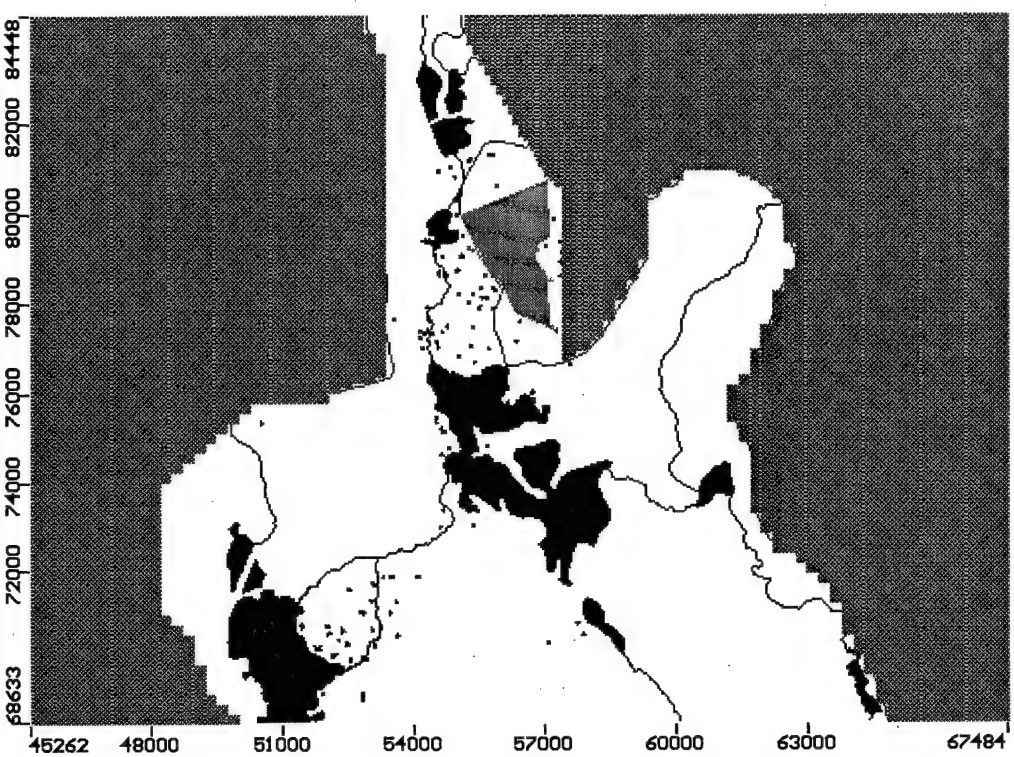

FIGURE 6 MODEL AREA

3.1.4.2 VERTICAL MODEL AREA

A cross-section of the model is shown in Figure 7. This is a close-up of the area from west to east through the landfill. Locations of wells and the elevations of the bottom of the outwash layer were input into Surfer, a program used to interpolate surfaces. Surfer performs grid-based contouring and three-dimensional surface plotting of graphics; in this project, Kriging was used for interpolation. In addition to the bottom of the outwash layer, the ground-surface elevation was also interpolated. This data came from both borehole data and USGS maps (USGS 1967, USGS 1970). These two grid files were imported as layers in the MODFLOW model.

Other layers were added to the model, keeping in mind what adjustable parameters or boundaries would be needed in the future. A ten foot fractured bedrock layer was added below the outwash layer because the site of the landfill used to be a rock quarry. Within the outwash layer, a thin layer was added to allow for a landfill liner. In addition, a thin layer over the entire region was allotted for a landfill cap. These provided flexibility for analysis on problems of the landfill.

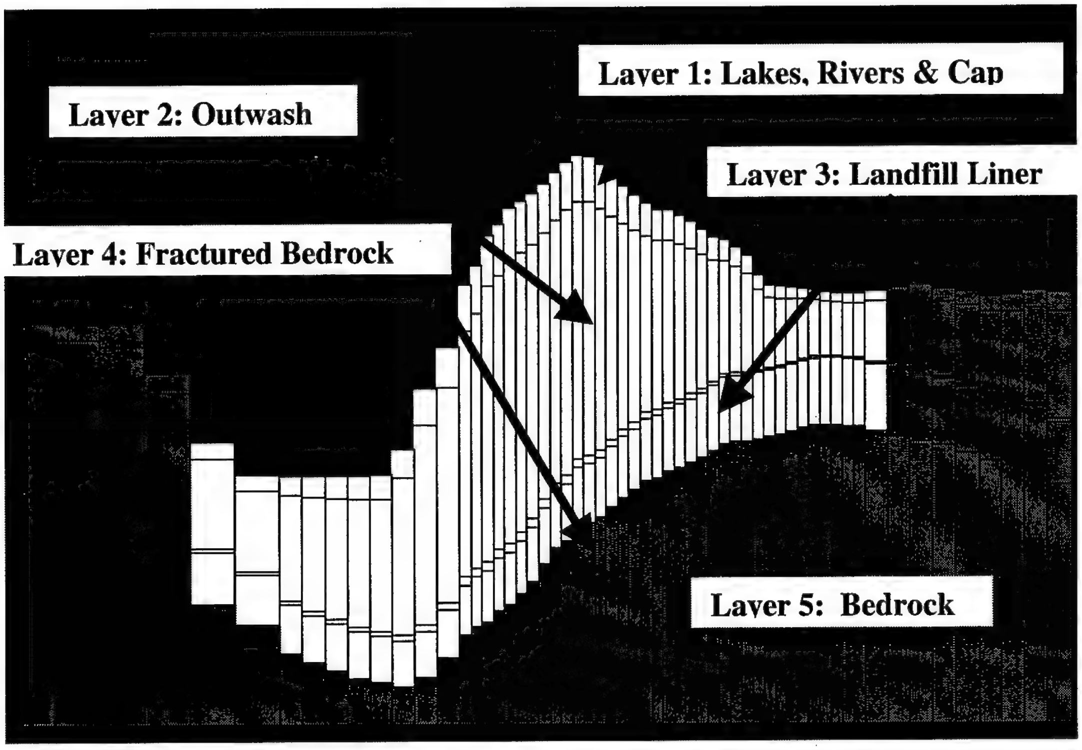

FIGURE 7 MODEL LAYERS

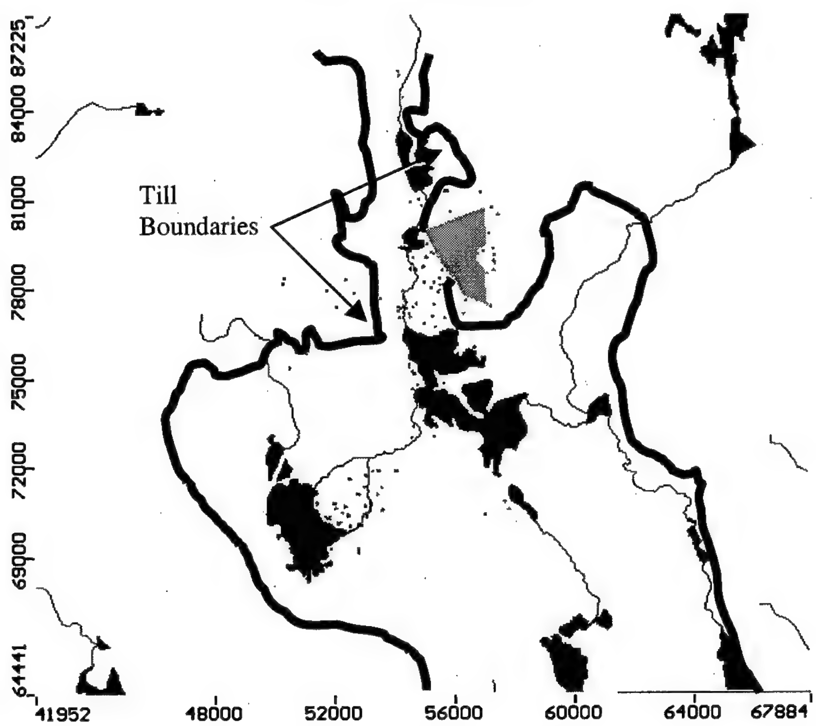

FIGURE 8 TILL BOUNDARIES

3.1.4.3 Model Boundary Conditions

The till boundaries, represented by the thick black lines in figure 8, are no flow boundaries. Although the landfill area sits on till according to the USGS map, that area was not assigned as no flow because rock quarrying operations within this area removed most of the material overlying the fractured bedrock beneath.

Lake Mirimichi, Turnpike Lake, Rabbit Hill Pond, Rabbit Hill Stream, the cranberry bogs, and Witch Pond, as well as other tributaries, were represented using the MODFLOW river package. River stage elevation was defined as the surface elevation. As required by the river package, conductances of the stream bed were assigned to individual cells using the following formula:

$$C = KLW/M$$

where C = conductance (ft^2/d)
K = conductivity of the river bed material (ft/d) (2 ft/d for rivers, 0.5 ft/d for lakes)
L = length of reach through cell (ft)
W = width of river in cell (ft)
M = thickness of river bed (1 ft for rivers, 5 ft for lakes)

3.1.4.4 Hydraulic Parameters

Preliminary values for aquifer parameters, such as hydraulic conductivity and recharge, were assigned according to accepted values for the geology and the area. These values are summarized in Table 4.

TABLE 4 INITIAL PARAMETERS

Layer	$K_x = K_y$ (ft/d)	K_z (ft/d)
1 (Outwash)	250	25
2 (Outwash)	250	25
3 (Outwash)	250	25
4 (Fractured Bedrock)	0.5	0.05
5 (Competent Bedrock)	0	0

3.1.4.5 Precipitation Recharge

Groundwater recharge initially was assigned as twenty-one inches per year, half of the average annual rate of precipitation over Massachusetts (USGS, 1984).

3.1.5 Model Calibration

After creating a model, it must be calibrated to ensure proper representation of the site. Calibration was accomplished utilizing quarterly data of water table elevations in monitoring wells. The heads predicted from the model were first compared to the heads measured in the field. Adjustments of the parameters were then made until the modeled heads were equivalent to the field heads. The June 1996 quarterly reports were chosen for calibration. The month of June was chosen because it has an average amount of yearly precipitation. The 1996 data were the latest available. Observation wells were placed in the model and the observed elevations of the water table from the quarterly reports were entered as observed elevations. The model provided an option to graph program-predicted groundwater levels in these wells versus observed values. A one-to-one correlation was desired. The final correlation is shown in Figure 9. The mean error was 1.5 feet; mean absolute error was 1.9 feet; RMS error was 2.04 feet. These errors are considered acceptable. Calibration parameters are listed in Table 5 below.

TABLE 5 PARAMETERS FOR CALIBRATION

Layer	Kx = Ky (ft/d)	Kz (ft/d)
1	250	25
2	250	25
3	250	25
4	1	0.1
5	0	0
Recharge = 21"/yr		

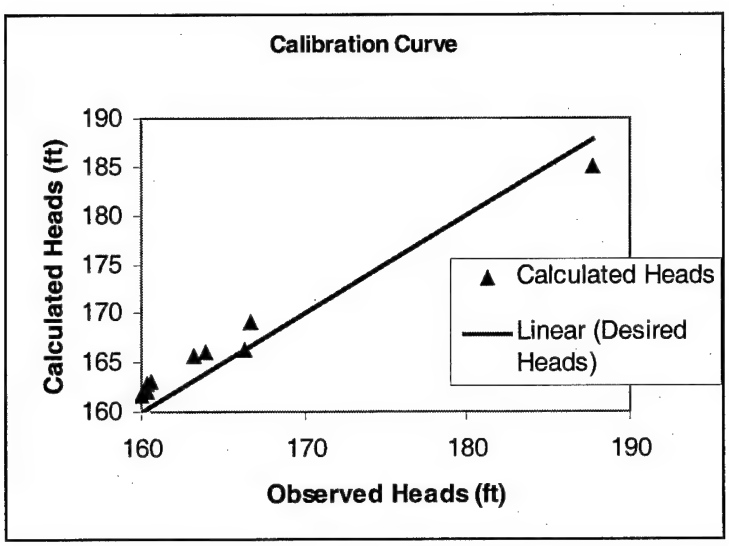

FIGURE 9 CALIBRATION CURVE

3.1.6 SENSITIVITY ANALYSIS

A sensitivity analysis was performed to evaluate the degree to which the base case values represent a unique solution. Various input parameters were changed to assess their impact on the model. If changing one parameter does not change the base case output, then the model is not considered sensitive to that particular parameter. Conversely, if the model is sensitive to a given parameter in this analysis, then that parameter needs to be close to the base case value for the model to remain in calibration. The sensitivity analysis was performed under steady-state conditions.

The sensitivity analysis was conducted by varying one input parameter at a time and comparing the predicted heads with those of the calibrated 'base-case' simulation. Parameters such as the recharge through landfill, the areal recharge, and each of the hydraulic conductivities of layers 2, 3 and 4 were varied by values between ten and one thousand percent of the base case. The results are tabulated in Table 6.

TABLE 6 RESULTS OF STEADY-STATE SENSITIVITY ANALYSIS

	Decreasing		**Base**	**Increasing**	
Recharge Through Landfill (in/yr)	0.1	0.5	1	2	10
Change Factor	0.10	0.50	1.00	2.00	10.00
Mean Error	1.40	1.41	1.45	1.43	1.51
Mean Absolute Error	1.90	1.90	1.92	1.91	1.97
RMS Error	2.01	2.02	2.05	2.03	2.11
Areal Recharge (in/yr)	4.2	10.5	21	31.5	42
Change Factor	0.20	0.50	1.00	1.50	2.00
Mean Error	1.07	1.20	1.45	1.62	1.83
Mean Absolute Error	1.66	1.75	1.92	2.07	2.26
RMS Error	1.76	1.86	2.05	2.19	2.37
Hydraulic Conductivity Layer 2 (ft/day)	25	125	250	500	2500
Change Factor	0.10	0.50	1.00	2.00	10.00
Mean Error	4.57	2.83	1.45	2.37	Error
Mean Absolute Error	5.09	3.29	1.92	2.77	Error
RMS Error	5.59	3.67	2.05	3.16	Error
Hydraulic Conductivity Layer 3 (ft/day)	25	125	250	500	2500
Change Factor	0.10	0.50	1.00	2.00	10.00
Mean Error	1.46	1.52	1.45	1.88	Error
Mean Absolute Error	1.94	1.98	1.92	2.30	Error
RMS Error	2.07	2.12	2.05	2.50	Error
Hydraulic Conductivity Layer 4 (ft/day)	0.1	0.5	1	2	10
Change Factor	0.10	0.50	1.00	2.00	10.00
Mean Error	1.42	1.41	1.45	1.43	1.58
Mean Absolute Error	1.90	1.90	1.92	1.91	2.04
RMS Error	2.02	2.01	2.05	2.04	2.18

Of the five parameters evaluated, the least sensitive were the recharges through the landfill, the areal recharge, and the hydraulic conductivities in layer 4. The recharge

on the landfill was changed by a factor of one-tenth and ten to simulate the different assumptions regarding infiltration rates through a landfill cover. There was little to no effect on the model as a result of this change. The areal recharge was varied to simulate the different precipitation conditions of the area. The hydraulic conductivity in layer 4 was changed by a factor of one-tenth then by a factor of ten, and again there was no significant head difference in the model. It seemed that as areal recharge was reduced by a factor of two tenths, the model achieved a lower mean error, meaning that the model was better calibrated. However, this observation could be misleading because that areal recharge is atypical for the New England area. Also the output results of groundwater flow from the model do not match the actual flow direction under these conditions. A combination of factors is required to achieve calibration, not just matching the steady-state targets given by the observation wells.

The most sensitive parameters were the hydraulic conductivities of layer 2 and 3. As expected, a high hydraulic conductivity would cause the groundwater elevations to rise above the surface. The predicted heads rose one foot above the base case heads when the hydraulic conductivity of layer 2 was twice that of the base-case. The model resulted in an error when run for conductivities ten times higher. This was probably due to groundwater head values exceeding the surface elevations, constant head boundaries, and the lake levels; the model was thus incapable of reaching steady-state. There were similar occurrences for layer 3 at higher conductivities. When the conductivity of layer 2 was lowered to one-tenth its value, the heads dropped by about three feet. This did not occur for layer 3.

3.2 Limitations

In evaluating this model, the following limitations should be noted:

1. Homogeneity of subsurface geology. The model simplifies the actual region and geologic parameters. Not only can the hydraulic conductivity vary within sediment type, but also it is not homogeneous throughout a particular layer. Patches of till lenses have been detected in boreholes.

2. Steady-state simulation. The model is only calibrated for a steady state simulation; it does not take into consideration the seasonal effects of precipitation and groundwater recharge.

3. Fixed properties for lakes and rivers. All river cells were assigned the same conductivities for riverbed and same depth as were the lake cells.

4. Assumed till boundaries and fractured bedrock extent at landfill. Where the till ends around the landfill and how thick and extensive the fractured bedrock layer is was up to the discretion of the modeler. Historical knowledge and current plume situation were taken into account in developing this simple, yet representative model of the area.

4. Interim Remediation System

4.1 System Design

The interim remediation plan was designed based on the results of Eckenfelder's groundwater flow and contaminant transport model. The major constituents in the groundwater contamination plume that require treatment are vinyl chloride and 1,4-dichlorobenzene. Since both of these contaminants respond well to volatilization, Eckenfelder chose to employ a series of air sparging wells located downgradient of the landfill as the interim remediation plan, Figure 10. The interim remediation design contains three lines of air sparging wells, downgradient of the landfill and intersecting the contamination plume in the overburden zone. The purpose of installing multiple lines of wells was to introduce redundancy into the system, and to decrease the time necessary to achieve lower constituent concentrations in the downgradient portion of the plume. At the present time only one line of wells has been constructed and is in operation. The proposed second and third series of wells are being held in reserve for further enhancement to the system if required (Laidlaw, Dec 1997).

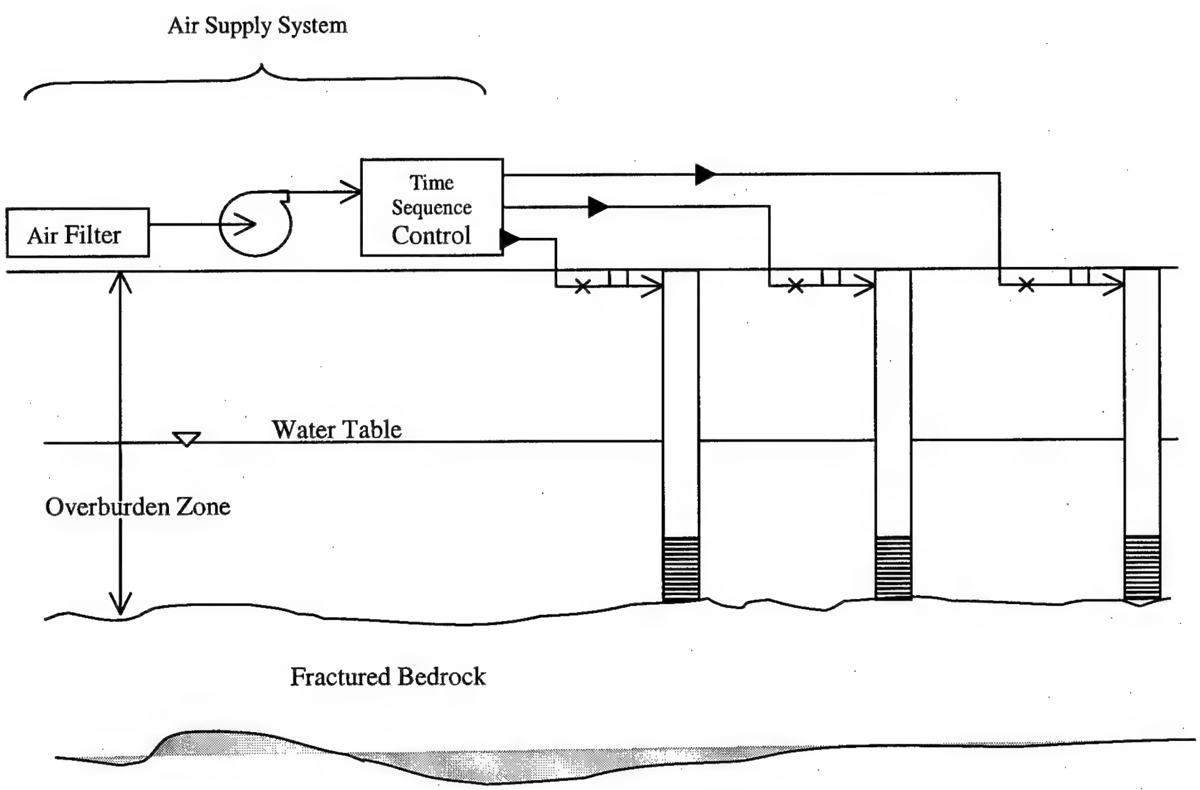

FIGURE 10: INTERIM AIR SPARGING SYSTEM SCHEMATIC

The air sparging wells pump air into the overburden zone of the subsurface. The air then percolates via bouancy upward through the subsurface causing volatilization of the vinyl chloride and 1,4-dichlorobenzene and promoting increased biodegradation. The

individual air sparging wells in the Plainville system will be operated intermittently to achieve greater efficiency, and to maximize the contribution of biodegradation to the treatment process. Each well will be operated for a period of approximately 12 hours followed by a rest period of 24 hours. Cycle frequencies will be adjusted during startup and /or during operation as required. The compressor will operate continuously because some wells will be injecting air while other wells are inactive (Laidlaw, Dec 1997). In the following sections, an overview of air sparging and the conditions necessary for the success of this technology are reviewed.

4.1.1 In-Situ Air Sparging

In situ air sparging (IAS) is an emerging remediation technology that involves injecting either air or oxygen under pressure into the saturated zone to volatilize groundwater contaminants and to enhance biodegradation in saturated and unsaturated soils by increasing subsurface oxygen concentrations (Miller, 1996, Otten, 1996). The oxygen injected below the water table volatilizes contaminants that are dissolved in groundwater, existing as a separate aqueous phase, and /or sorbed onto saturated soil particles. The rate of contaminant removal by volatilization depends upon the degree of contact between the injected air and the contaminated groundwater. Initial rapid contaminant removal occurs as the VOCs closest to the rising air are volatilized. Subsequent removal occurs more slowly because contaminants must diffuse to the rising air before volatilization can take place. When this latter stage of volatilization occurs, enhanced biodegradation due to the increased oxygen level in the subsurface helps to keep contaminant removal rates up. Volatile organic compounds having a Henry's Law constant of 0.05 or larger respond well to air sparging (Wilson, 1994).

Volatilized vapors from the sparging operation migrate via buoyancy into the vadose zone where they are extracted by vacuum, generally by a soil vapor extraction system. A typical air sparging unit consists of horizontally or vertically placed sparging wells, shut off valves, and one of two sparging methods: a compressor which feeds a pressure vessel which in turn periodically injects air or direct injection of air via a ventilator. The term biosparging is sometimes used interchangeably with air sparging to highlight the bioremediation aspect of the treatment process or to refer to situations where biodegradation is the dominant remedial process with volatilization playing a secondary role (Miller, 1996). The principle advantages of IAS are that it is inexpensive to install and operate, it targets pollutants in the saturated and smear zones, and it can achieve more thorough mass removal in a shorter time than other technologies (Elder, 1998).

The air sparging system designed for the Plainville landfill consists of vertical wells and does not include a soil vapor extraction system. Eckenfelder calls this system a biosparging system, but it is, in fact, an air sparging system since stripping of contaminants through volitilization is the primary removal mechanism with biosparging playing a secondary role in treatment. In section 4.1.2, the system's performance will be evaluated by observing changes in the constituent concentrations in the monitoring wells down gradient. This evaluation will be based not only on changes in the constituent concentrations but also on changes in conditions that affect biodegradation; dissolved oxygen, redox potential, iron II, and manganese II.

4.1.1.1 Site Conditions

Successful use of air sparging technology depends on the ability of the system to effectively deliver air to the treatment area, and the ability of the subsurface materials to effectively transmit the air. Therefore, the soil in the saturated zone must be loose enough to allow the injected air to readily escape up into the unsaturated zone. Loose soil conditions include relatively coarse-grained (moderate to high permeability) homogeneous overburden materials that foster "effective contact" between air and media being treated. Fine grained, low permeability soils limit the migration of air in the subsurface, thereby limiting the effectiveness of air delivery and vapor recovery. In addition, heterogeneity, due to lithologic variations or fractures, may also limit the effectiveness of this technology. In addition, relatively large saturated thickness and depths to groundwater greater than five feet may also be required for successful applications of air sparging. The depth of the saturated thickness and the depth below the water table at which air is injected are factors that determine the area of influence of a sparging well (Miller, 1996).

The Plainville Landfill site consists primarily of glacial outwash, which is medium grained highly conductive material, in the overburden zone, and fractured bedrock which lies underneath the outwash layer. Lenses of glacial till, which are relatively impermeable, are located throughout the glacial outwash layer. These lenses will reduce the effectiveness of the air sparging system, and may potentially cause the contaminant plume to spread.

4.1.1.2 Contaminants

As noted previously, various volatile, semivolatile, and nonvolatile organic contaminants in dissolved, free-phase, sorbed, and vapor phases can be treated using air sparging. Some contaminants affected by volatilization and biodegradation processes of air sparging include fuels such as gasoline, diesel, and jet fuels; oils and greases; BTEX compounds; and chlorinated solvents (Miller, 1996). Contaminants with higher Henry's Law constants will volitilize due to advective air flow faster and more efficiently than contaminants with a lower Henry's Law constant. Vinyl chloride has a Henry's Law Constant of 22.38 L-atm/mol and responds quite well to air sparging. The other contaminant of interest in this study, 1,4-dichlorobenzene, has a Henry's Law constant of 2.24 and may not respond as well as Vinyl chloride.

4.1.1.3 Methodology

"Implementation of a safe and successful air sparging project requires a detailed site investigation including site-specific determination of air flow patterns in the unsaturated zone and conditions relating to the feasibility of bioremediation" including nutrient concentrations, contaminants at levels toxic to microbes, dissolved oxygen etc. (Miller, 1996). A pilot-scale test is generally performed to assess assumptions to be used in the design of the full-scale remediation system and to determine effective air flow rates and injection pressures.

The network of air injection wells are designed so that all of the area requiring treatment is effectively aerated. This typically involves establishing overlapping zones of

influence for the sparging well network. The radius of influence can vary widely, particularly in stratified, finer soils. Within coarse material, where airflow is more controllable and predictable, injected air will tend to rise in the form of an almost parabolic plume to the vadose zone. The radius of influence will increase with the depth of injection. Deeper injection, however, requires a higher injection pressure (Otten, 1996). Air is pumped into the subsurface either continuously or in cycles. Cycling the injection of air into the subsurface helps to promote bioremediation in the subsurface, and also helps to prevent the spread of the plume due to decreased conductivity. If air is injected continuously, preferential channels will form. The degree to which this happens depends on the soil type and injection pressure. To prevent the formation of channels, air should be injected only for a short time (1 to 5 min), and be followed by a longer period of standstill (10 to 60 min).

> "Improperly controlled air sparging systems can pose significant health and safety risks. The pressurized air can accelerate the uncontrolled migration of contaminated vapors and the consequent accumulation in buildings or other vapor receptors. It has been suggested that there may also be the potential for enhanced spreading of dissolved contaminant plumes as the injected air initially displaces groundwater. In addition, it has been suggested that the air injection may result in increased mixing, and therefore, increased mass transfer of contaminants into groundwater. To minimize the risk of uncontrolled vapor or groundwater migration components, the following measures should be considered for effective and safe operation:
>
> a) concurrent installation of a soil vapor extraction system to capture the entire volume of contamination vapors; and
> b) containment of groundwater in the air injection zone to prevent off-site migration of dissolved contaminants.
>
> In addition to the health and safety risks, another concern is that air sparging may lead to modified aquifer conditions such as aquifer plugging because of iron precipitation stimulated by increased oxygen levels." (Anderson, 1994)

The interim remediation system designed for the Plainville Landfill did not involve a site investigation.

4.1.2 QUARTERLY TESTING RESULTS

Since the Plainville Landfill has been accepting waste, there has been quarterly testing performed at the site. The following analysis will only pertain to the last six years of quarterly testing from 1993 through 1998. As stated previously, the results of these tests indicate that two contaminants, vinyl chloride and 1,4 dichlorobenzene, have consistently been present in concentrations above the MMCL. Figures 11 through 14 illustrate the contamination trends for the past six years. The interim remediation system has been in operation since the first

quarter of 1998. As is indicated on these graphs, the overburden contaminant constituents show a relatively pronounced reduction in concentration since the air sparging system has been in operation. The concentration of vinyl chloride in the bedrock also shows a reduction due to the overburden air sparging wells. The 1,4-dichlorobenzene concentrations in the bedrock show only a slight downward trend.

The reduction of vinyl chloride concentrations in the fractured bedrock may be caused by two possiblities. First, the air sparging wells could be located right on top of, or next to, a fracture in the bedrock. Since there is less resistance in the fracture than there is in the outwash soil, air could be forced by the injection pressure into the fractures, thus reducing contaminant concentrations in this zone. Secondly, several lenses of till are known to exist throughout this location. The air could be getting injected between the till lenses and the fractured bedrock. This would, again, cause a reduction of contaminants in the fractured bedrock layer.

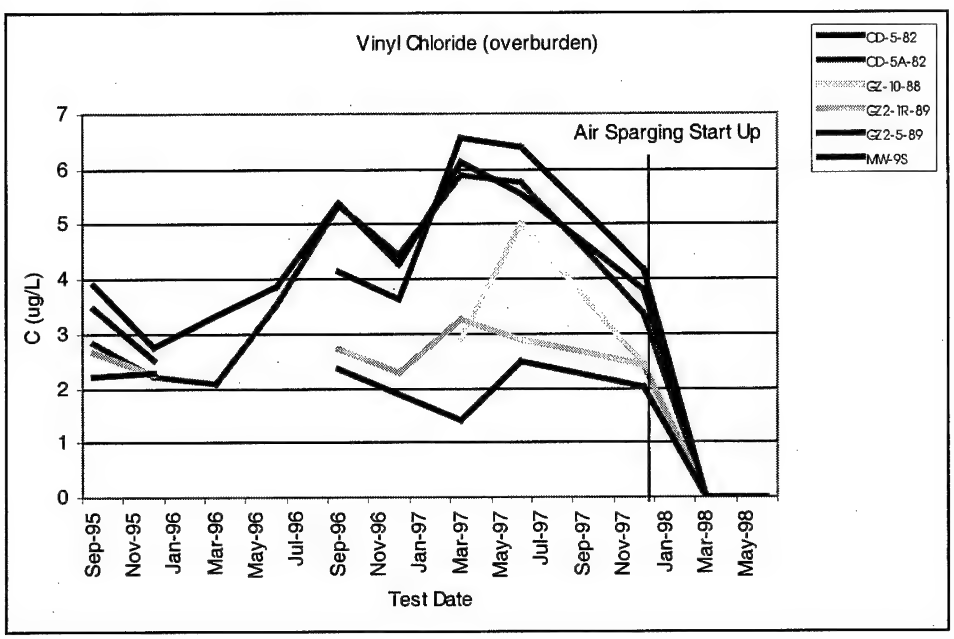

FIGURE 11 VINYL CHLORIDE CONCENTRATIONS IN THE OVERBURDEN ZONE

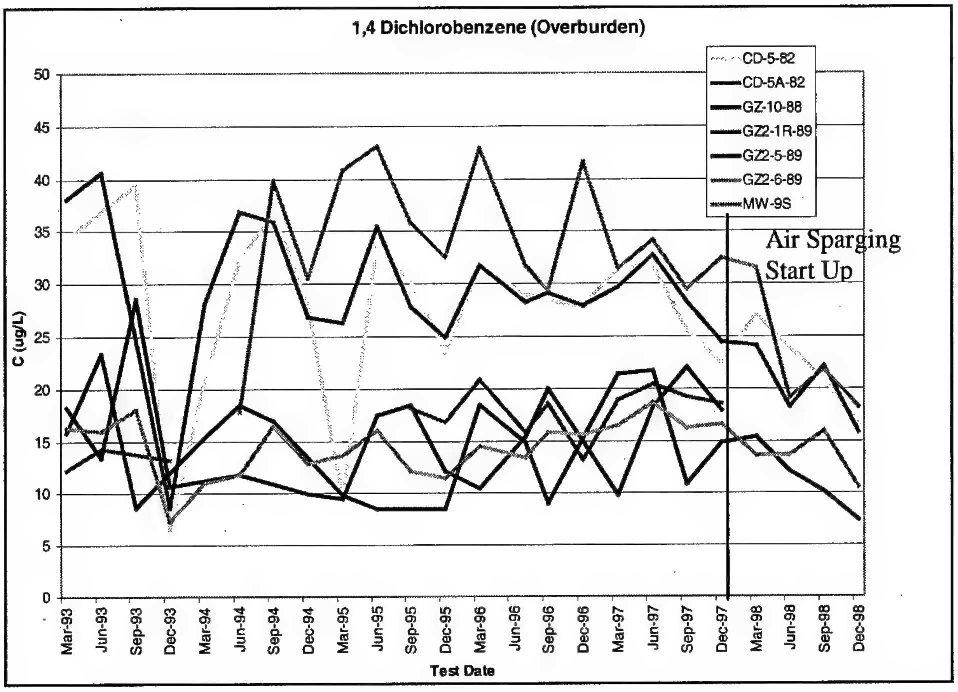

FIGURE 12 1,4-DICHLOROBENZENE CONCENTRATIONS IN THE OVERBURDEN ZONE

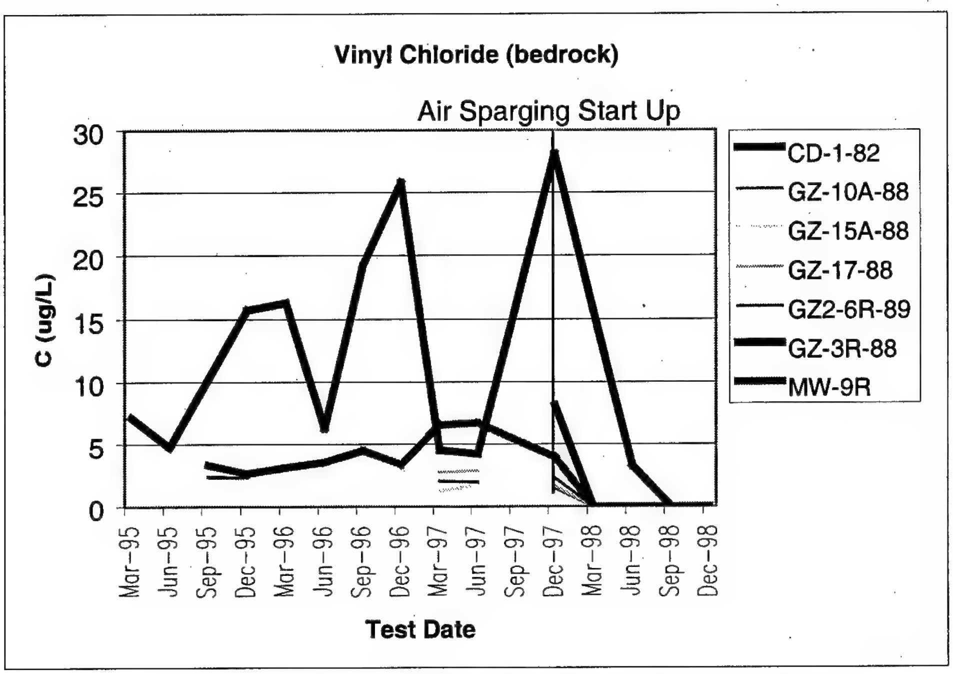

FIGURE 13 VINYL CHLORIDE CONCENTRATIONS IN THE BEDROCK

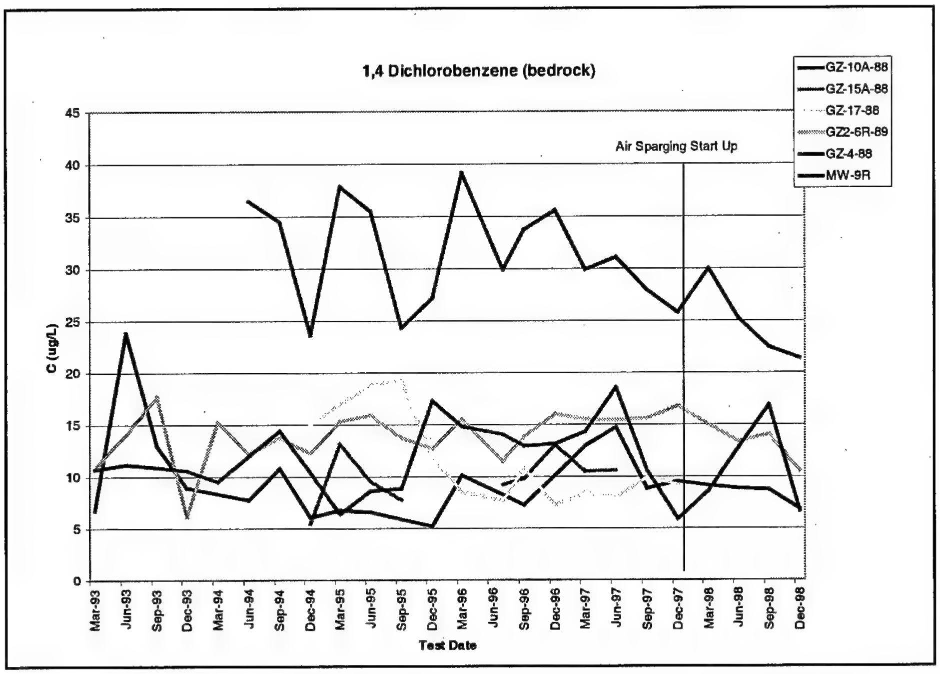

FIGURE 14 1,4-DICHLOROBENZENE CONCENTRATIONS IN THE BEDROCK

4.2 POSSIBLE ASSUMPTION/PROBLEMS WITH THE INTERIM REMEDIATION DESIGN

The MODFLOW groundwater models developed by Eckenfelder and for this project are unable to predict the radius of influence of an air sparging well. Also, Eckenfelder did not design a vapor extraction system for the volatile emissions that will be produced through air sparging. In addition, Eckenfelder utilized removal efficiencies developed by David Wilson of Vanderbilt University. These removal efficiencies are based on the assumption of paraboidal flow fields utilizing air bubbles around each well. This assumption has not held true in actual field tests. Lastly, Eckenfelder did not take into account the lenses of glacial till that are present throughout the glacial outwash layer. Problems that may arise from these assumptions will be discussed in further detail in section 4.3.

4.3 ANALYSIS

MODFLOW is unable to predict the radius of influence for an air sparging well. The only way to ascertain the extent of the area affected by the injected air is to perform a field test at the specific remediation site. This knowledge is essential in determining the usefulness of the air sparging system. Although this system is already operational and quarterly testing reports indicate good volatilization of vinyl chloride, field testing to indicate the subsurface flow patterns of the injected air could provide a more accurate estimate of the remediation time at this site.

Initial tests of the air quality near the sparging system indicated contaminant levels below the mandated limits for air quality. However, because a vapor extraction system has not been installed at this site, air quality testing should be conducted during quarterly testing to ensure that air quality standards remain below regulatory requirements.

Experimental results have shown that air bubble flow occurs in "water saturated, coarse grained material, while air channeling is typically observed in fine-grained soils" (Marulanda, 1998). Several field tests have indicated that, in fact, channeling is the predominant air flow pattern in most geologic media (Barvenik, 1999). Since the effectiveness of air sparging systems is essentially controlled by the degree of contact between the injected air and the contaminated soil, the presence of paraboidal air bubble flow or channels will greatly change the removal efficiencies achieved with the air sparging system. Again, field tests of the existing system should be conducted to more accurately determine the remediation time appropriate for this site.

The glacial outwash valley located to the west of the landfill where the contaminant plume is located contains many till lenses. These till lenses range in thickness from approximately one foot to ten feet and are located at various depths. The till lenses have a much lower conductivity than the surrounding outwash material. Consequently, this will cause the contaminants, as well as the injected air, to flow around, under and over these areas. Also, if the air is injected below one of these lenses it could become trapped. If the air does become trapped, pockets of contamination could realistically pass over the till lenses without any volatilization taking place. The presence of these till lenses will result in a complete disruption of the air flow pattern and a marked increase in cleanup times (Marulanda, 1998, Wilson, 1994). A field test on the existing interim air sparging system could determine where the injected air was surfacing, and whether the till lenses were causing corridors of contaminated groundwater to escape volitilization. This would enable them to more accurately predict the removal efficiencies of the interim remediation system and possibly determine if additional air sparging wells were required. Figure 15 illustrates the air flow pattern in the subsurface and the effect of till lenses on this air flow.

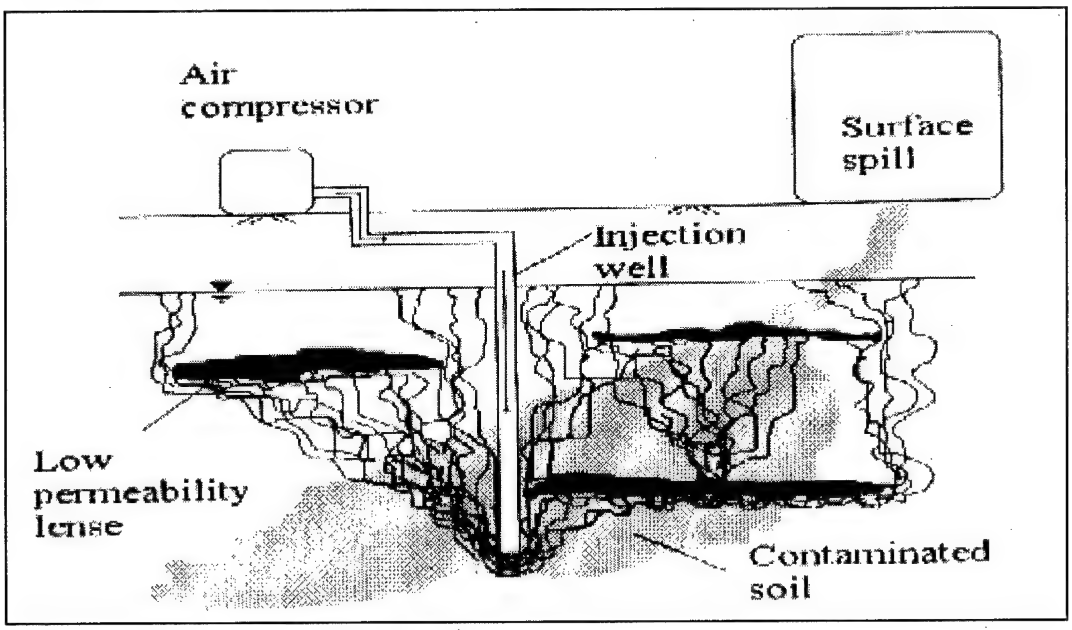

FIGURE 15 SCHEMATIC OF AIR SPARGING SYSTEM (MARULANDA, 1998)

5. Final Remediation System

5.1 System Design

The proposed final remediation design will consist of the overburden air sparging wells, an additional nine upper bedrock air sparging wells, five groundwater extraction wells located upgradient of the air sparging wells, five re-injection wells located approximately 75 feet downgradient of the air sparging wells and a treatment facility for the extracted groundwater, Figures 16 and 17. The integrated groundwater treatment system is designed to control groundwater along the southwest corner of the landfill, in an effort to reduce contaminant concentrations to a level below the MMCL before it leaves the landfill property. Eckenfelder designed this system based on the results of site investigations, groundwater monitoring, aquifer pumping tests, MODFLOW modeling, and treatability studies (Eckenfelder, 1998).

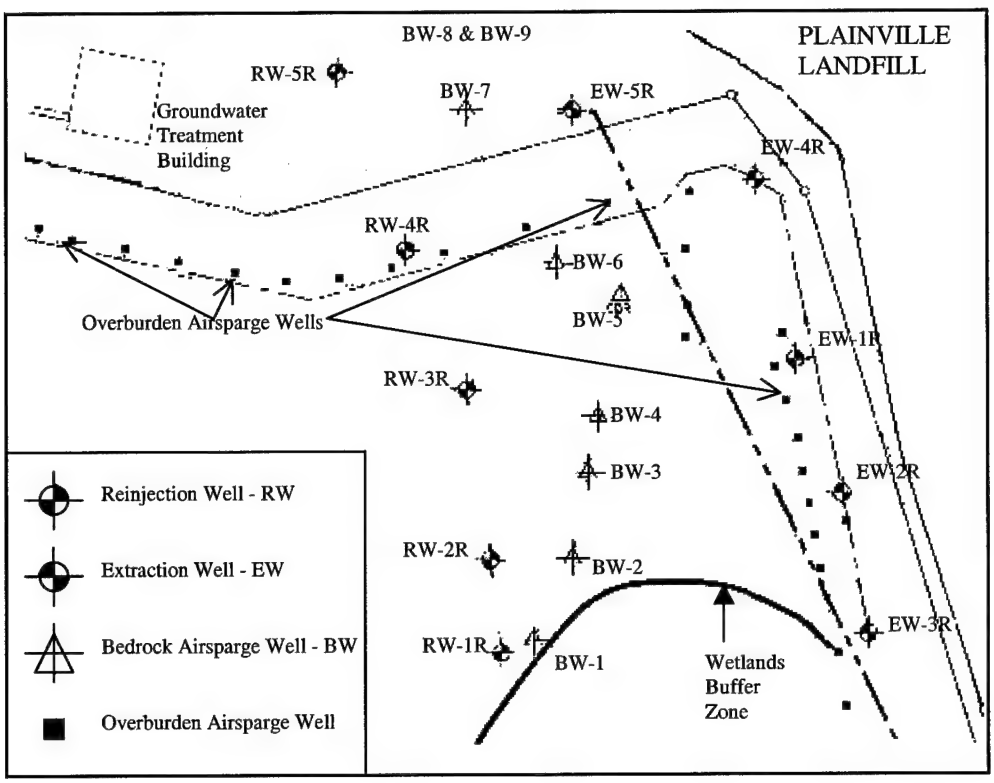

Figure 16 Final Remediation Design (Eckenfelder, 1998)

5.1.1 Extraction Wells

The five groundwater extraction wells will be installed in the deep competent bedrock with a 50-foot long open bedrock interval (The wells will not be screened). They are designed to pump at a total combined rate of 20 gallons per minute and are

expected to draw contaminated water from each of the three layers, overburden, fractured bedrock, and competent bedrock. The reinjection wells are designed with six-inch diameter, black steel casings grouted into the bedrock (Eckenfelder, 1998).

5.1.2 Treatment Facility

Contaminated groundwater from the extraction wells will be pumped to the treatment facility where it will be directed to an aerated equalization tank. The aeration will provide necessary oxidation of iron as well as the removal of vinyl chloride. The aeration tank is designed for removal of iron to prevent fouling of the granular activated carbon (GAC) columns and the reinjection wells. Based on titration tests, Eckenfelder determined that the optimal pH for iron removal was 7.5 and will add sodium hydroxide to the aeration tank to achieve this pH. The reduced iron water from the aeration tank will discharge into bag filters for removal of precipitated iron and then on to GAC columns for removal of 1,4-dichlorobenzene. The effluent from the GAC column will then be reinjected into the subsurface via the reinjection wells. The capacity to inject sodium hypochlorite following the GAC columns has been provided to allow for control of biological fouling in the reinjection wells (Eckenfelder, 1998).

5.1.3 Reinjection Wells

The five treated-water reinjection wells will be installed across both the fractured and competent bedrock layers, approximately 75 feet downgradient of the biosparge wells. They will pump at a total combined rate of 20 gallons per minute. These wells are designed with non-metallic, six-inch casings to limit the growth of iron bacteria, which can significantly reduce the long-term effectiveness of the wells. The wells are designed with stainless steel screens over the fractured and competent bedrock water-bearing zones (Eckenfelder, 1998).

5.1.4 Bedrock Biosparging Wells

The nine bedrock biosparge wells will be installed and screened over the fractured and competent bedrock layers. Separate casings/screens will be used for the two zones. These wells will be operated intermittantly to achieve greater efficiency and to maximize the contribution of biodegradation to the treatment process. The operational period of these wells is estimated to be 12 hours with a 24 hour rest period. Cycle frequencies will be modified during operation based on system performance (Eckenfelder, 1998).

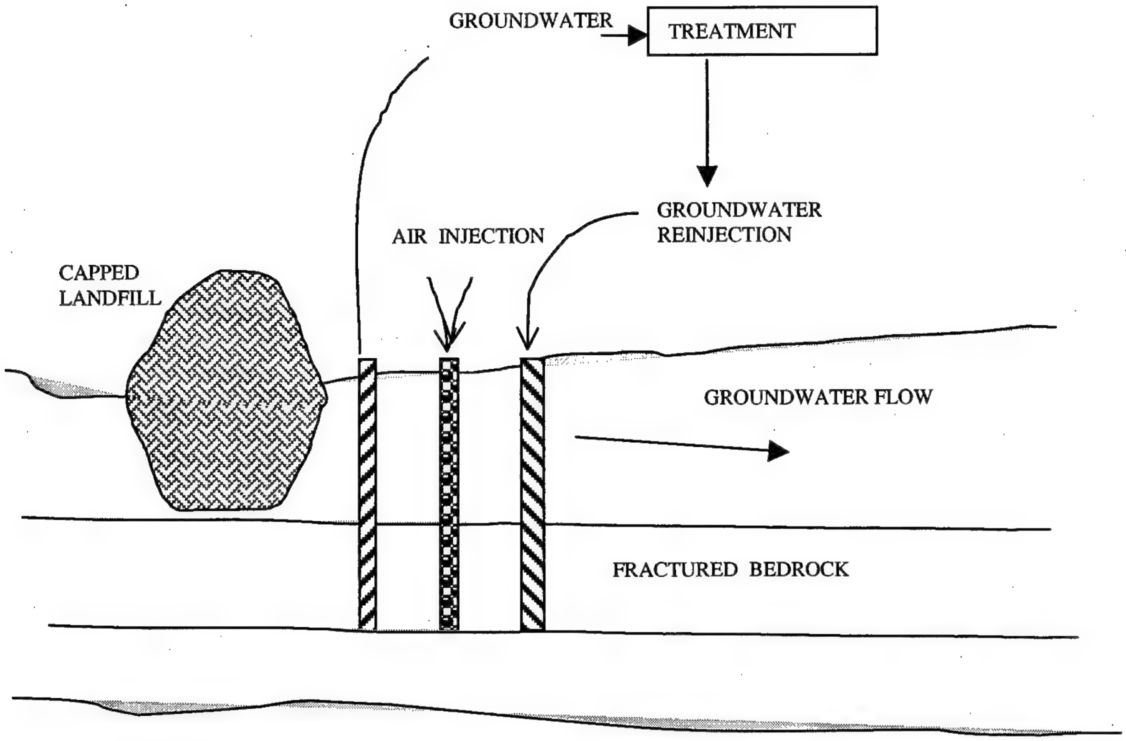

FIGURE 17 CROSS SECTION OF FINAL REMEDIATION SYSTEM DESIGN

5.2 POSSIBLE ASSUMPTIONS/PROBLEMS WITH FINAL REMEDIATION SYSTEM DESIGN

Eckenfelder utilized his groundwater model to determine the effective removal rate of vinyl chloride and 1, 4-dichlorobenzene before the plume crosses the site boundary. However, his model was run in steady state, assuming that the source of the contamination from the landfill was neither increasing nor decreasing. Secondly, Eckenfelder assumed that the area of influence for each well corresponded to the size of the cell in which they were located in the model. This area of influence is equivalent to a radius of influence of 12.5 feet, which corresponds to a radius of influence at several sites studied by the American Petroleum Institute. There are several problems with this assumption. First, inherent variability in soil conditions between sites makes it almost impossible to use predictions from other site studies to design a system for this site. Second, to utilize the size of the model cell as the basis for the wells radius of influence without any scientific or analytical verification is convenient but not justifiable (Culligan, 1998). Third, the screening of the extraction and reinjection wells across both the fractured and competent bedrock is suspect. Also, the bedrock biosparging wells were designed utilizing the assumption that bedrock acts like gravel. However, this assumption neglects the fact that bedrock is riddled with fractures that will allow air flow along them instead of creating the optimal curtain in the soil. Lastly, the quarterly monitoring reports indicate that wells number GZ-4-88, which is located north of the landfill, and CD-1-82, which is located north east of the landfill, indicate concentrations

of 1,4-dichlorobenzene in the bedrock that exceed the MMCL. The current remediation schemes both interim and final, do not address this contamination or its possible causes.

5.3 Analysis

The MODFLOW model was utilized to investigate the above mentioned discrepancies in the proposed extraction and reinjection wells. Several simulations with different pumping rates for the different wells were investigated. For the biosparging wells, an extensive literature review was conducted to ascertain field practices and results. The assumption that fractured bedrock acts like gravel, as well as the other discrepancies with the airsparging system design, were addressed during this review. The ultimate goal of any treatment system in this area is to attenuate the groundwater contaminant concentrations to levels below their respective MMCLs. An ancillary benefit to these systems will be the reduction of other volatile organic compounds that do not exceed their respective MMCLs.

5.3.1 MODFLOW Analysis

As noted previously, Eckenfelder designed the five pumping and reinjection wells to pump at a total combined rate of 20 gallons per minute. This corresponds to a pumping rate of 4 gallons per minute per well. Figure 18 illustrates the MODFLOW results achieved with this pumping rate and Figure 19 illustrates the capture curve.

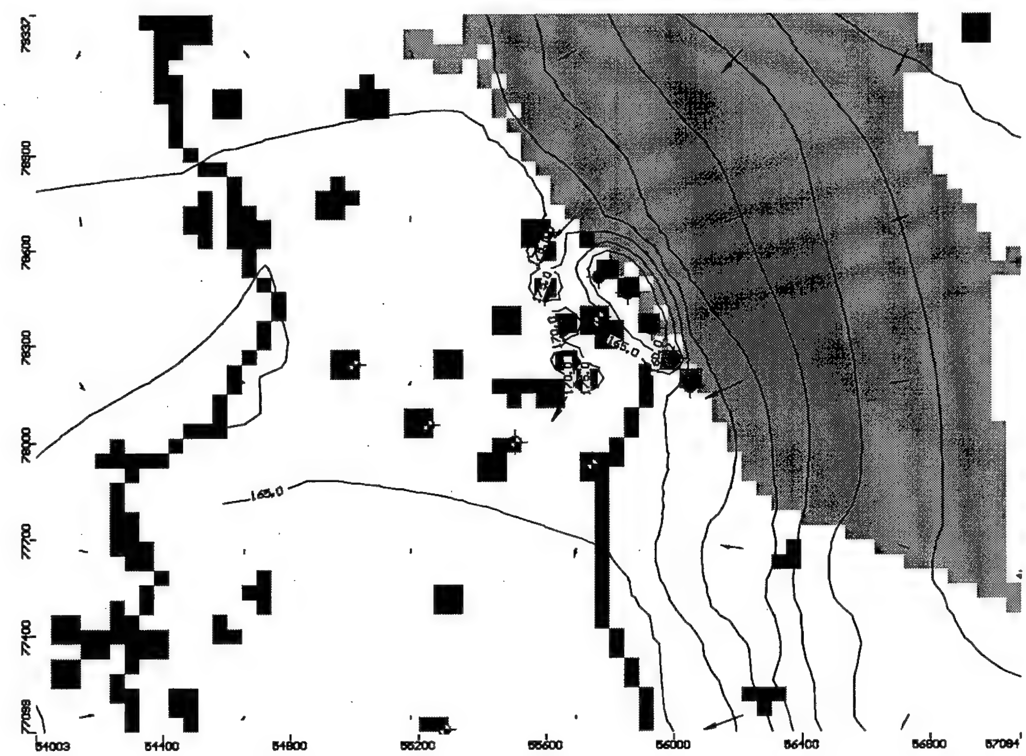

Figure 18 MODFLOW results. Pumping rate - 4 GPM

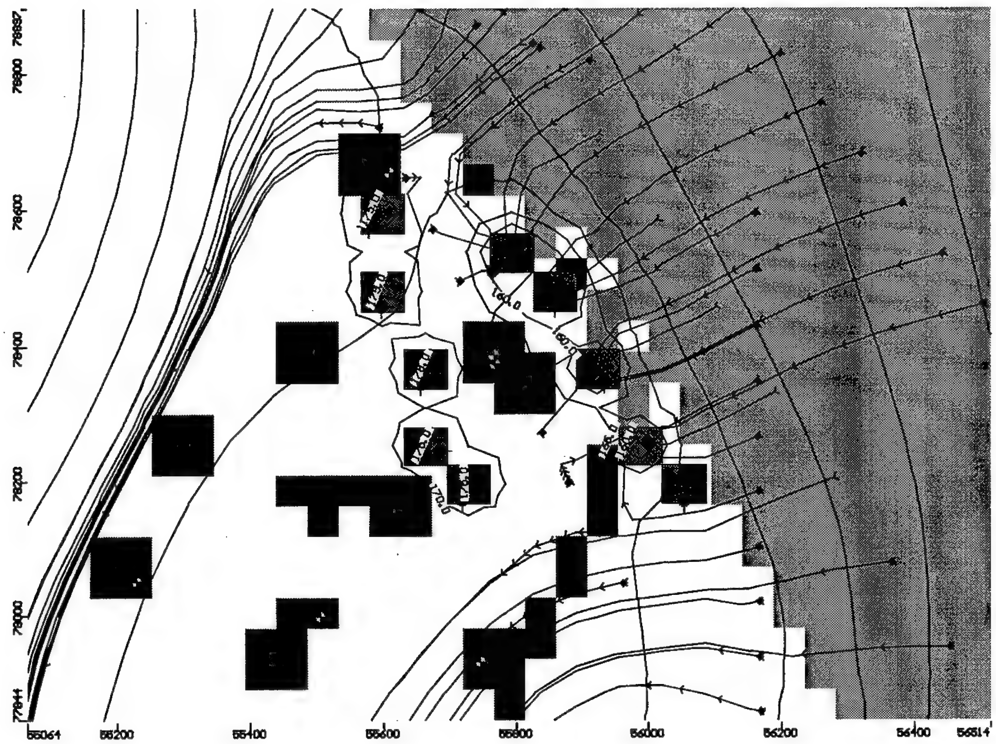

FIGURE 19 CAPTURE CURVE. PUMPING RATE – 4 GPM

A pumping rate of four gallons per minute does appear to achieve an adequate capture zone. The most southerly and northerly wells appear to allow contaminants to escape the capture zone. Contaminants in the most northerly and southerly portions of the plume show lower concentrations, than the middle of the plume. This is probably due to the fact that they were spread to these locations through dispersion and advection. Consequently, when the pumping wells are in operation, this spreading will be eliminated. The reinjection wells do not appear to create a curtain to help stop the spread of the contaminant plume down gradient. There are gaps between the wells. However, this lack of a curtain is not essential to the design of an effective remediation system.

Pumping rates of 5, 10 and 20 gallons per minute per well were also analyzed with the MODFLOW model. Figures 20, 21 and 22 illustrate the outputs achieved for these runs. Since the designed pumping rate appears to effectively capture the plume as it escapes from the landfill these higher pumping rates are not recommended. However, increased monitoring along the southern side of the known plume should be conducted to ensure that the contamination plume does not migrate southward and escape remediation.

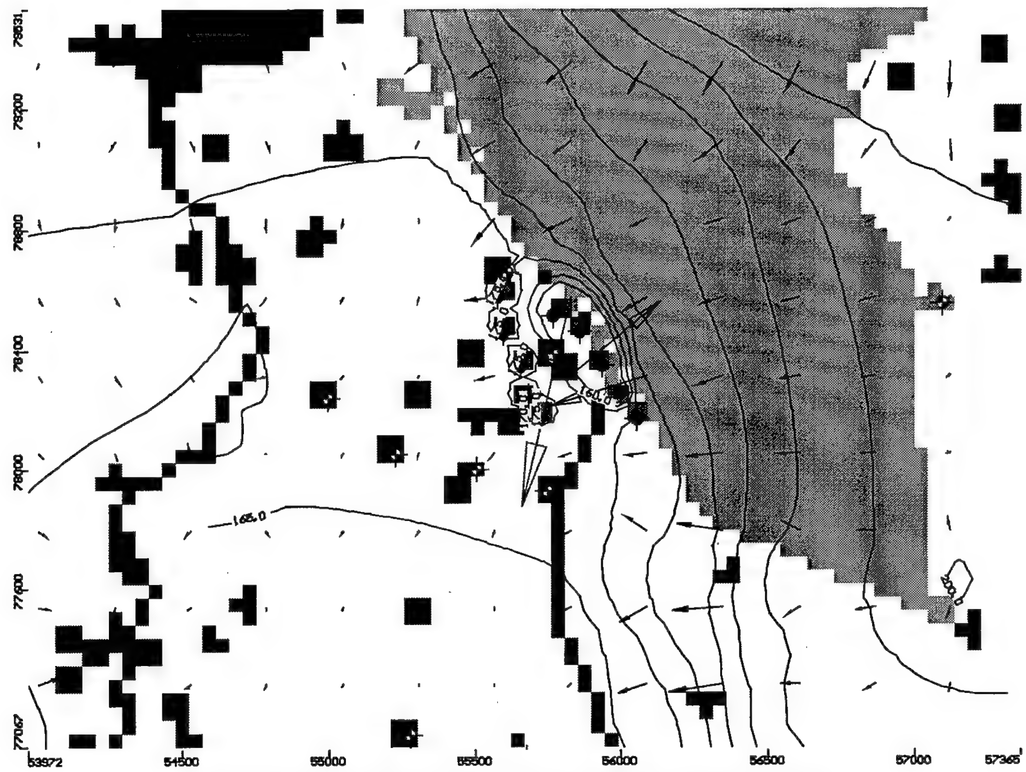

FIGURE 20 MODFLOW RESULTS. PUMPING RATE – 5 GPM

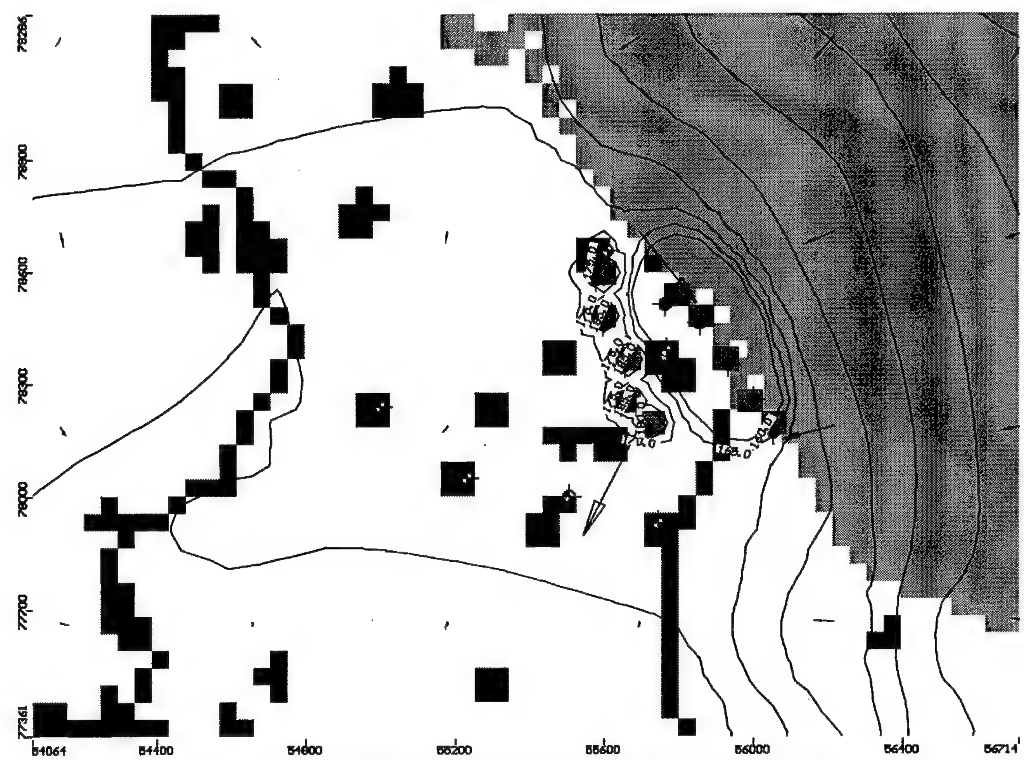

FIGURE 21 MODFLOW RESULTS. PUMPING RATE – 10 GPM

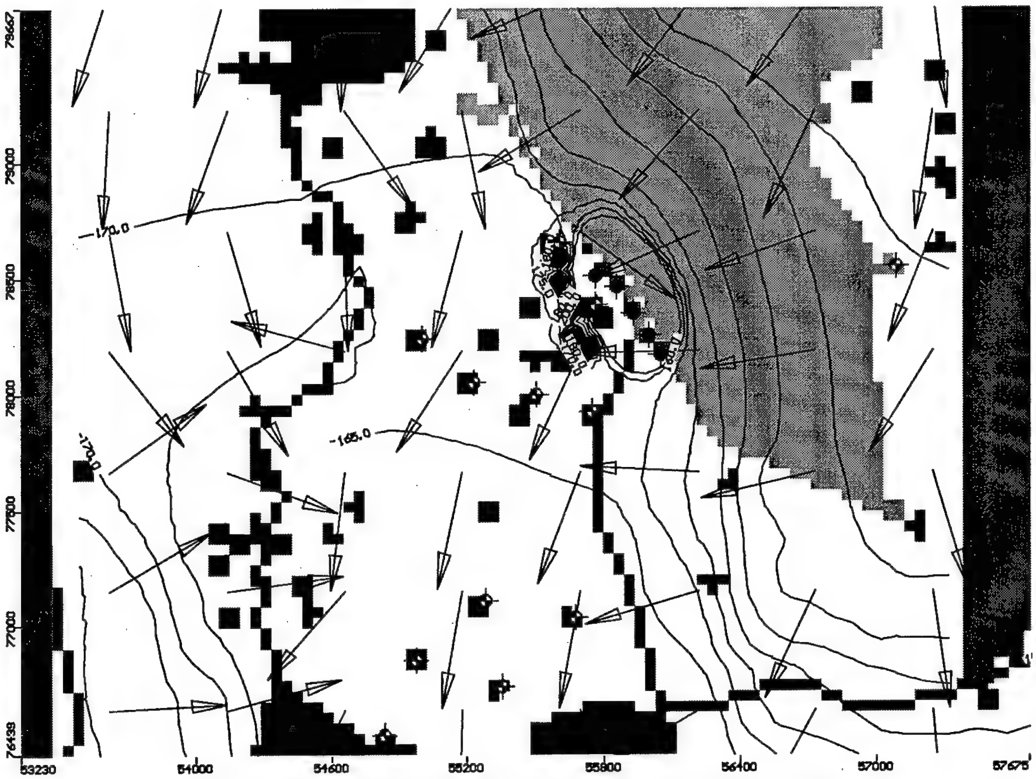

FIGURE 22 MODFLOW RESULTS. PUMPING RATE – 20 GPM

5.3.2 SYSTEM ANALYSIS

The assumption that the source of contamination was neither increasing not decreasing is incorrect. The results from quarterly testing indicate a one-third reduction in the concentration of 1,4-dichlorobenzene from 1997 to 1998. Consequently, Eckenfelder's use of the MODFLOW model to determine effective removal rate is adequate.

As was discussed previously, the presence of till lenses throughout the clean up zone will reduce the efficiency of the remediation system. MODFLOW is not flexible enough to allow the input of till lenses. Consequently, it can not be utilized to analize this feature. Since the extraction wells are located relatively close to the landfill, the effect from the lenses should be reduced.

Eckenfelder proposed to extract water from the overburden, fractured bedrock, and competent bedrock layers. Extracting water from the overburden and fractured bedrock layers where the plume is located is adequate. However, extraction from the competent bedrock will likely cause a spread of the contamination into this zone. Extraction from just the overburden and fractured bedrock layers should mitigate the contamination in the groundwater.

Assuming that fractured bedrock will produce the same flow patterns as gravel is inaccurate. Air flow in fractured bedrock will travel along the fractures. Once the air reaches the overburden zone it will then spread out in channels as was discussed in section 4.3. Consequently, trying to determine a radius of influence for bedrock air sparging wells by assuming the wells are located in gravel serves no practical purpose.

As was illustrated earlier in figures 11 through 14, the overburden air sparging wells are mitigating contaminants in the fractured bedrock layer. The observed reduction of contaminant concentrations in the fractured bedrock may arise from two causes. First, the air sparging wells could be located right on top of, or next to, a fracture in the bedrock. Since there is less resistance in the fracture than there is in the outwash soil, air could be forced by the injection pressure into the fractures, thus reducing contaminant concentrations in this zone. Secondly, several lenses of till are known to exist throughout this location. The air could be getting injected between the till lenses and the fractured bedrock. This would, again, cause a reduction of contaminants in the fractured bedrock layer. Consequently, the need for bedrock air sparging wells is questionable.

Lastly, the contamination noted in wells GZ-4-88 and CD-1-82 has not been addressed by the remediation design. This contamination may be due to chemical dispersion. However, there could be other explanations for this source of contamination. Further study into this area should be addressed.

6. CONCLUSIONS

As was noted in sections 4.3 and 5.3, there are several discrepancies with the interim and final remediation systems. The presence of till lenses throughout the remediation zone is not addressed. These lenses could reduce the efficiency of the remediation system and increase mitigation times. The extraction of water from the competent bedrock layer also appears to be suspicious. The possible spreading of the contamination into the competent bedrock should be addressed before this system is installed. In addition, the air sparging system should be field tested to ascertain the flow pattern in the subsurface. Quarterly testing seems to indicate that the overburden system is adequately treating the contaminants. However, the till lenses could be reducing the systems efficiency. Finally, the installation of the bedrock air sparging wells should be reconsidered.

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8. Appendix A

1,4-Dichlorobenzene Plumes in the Overburden Zone - 1997 and 1998.

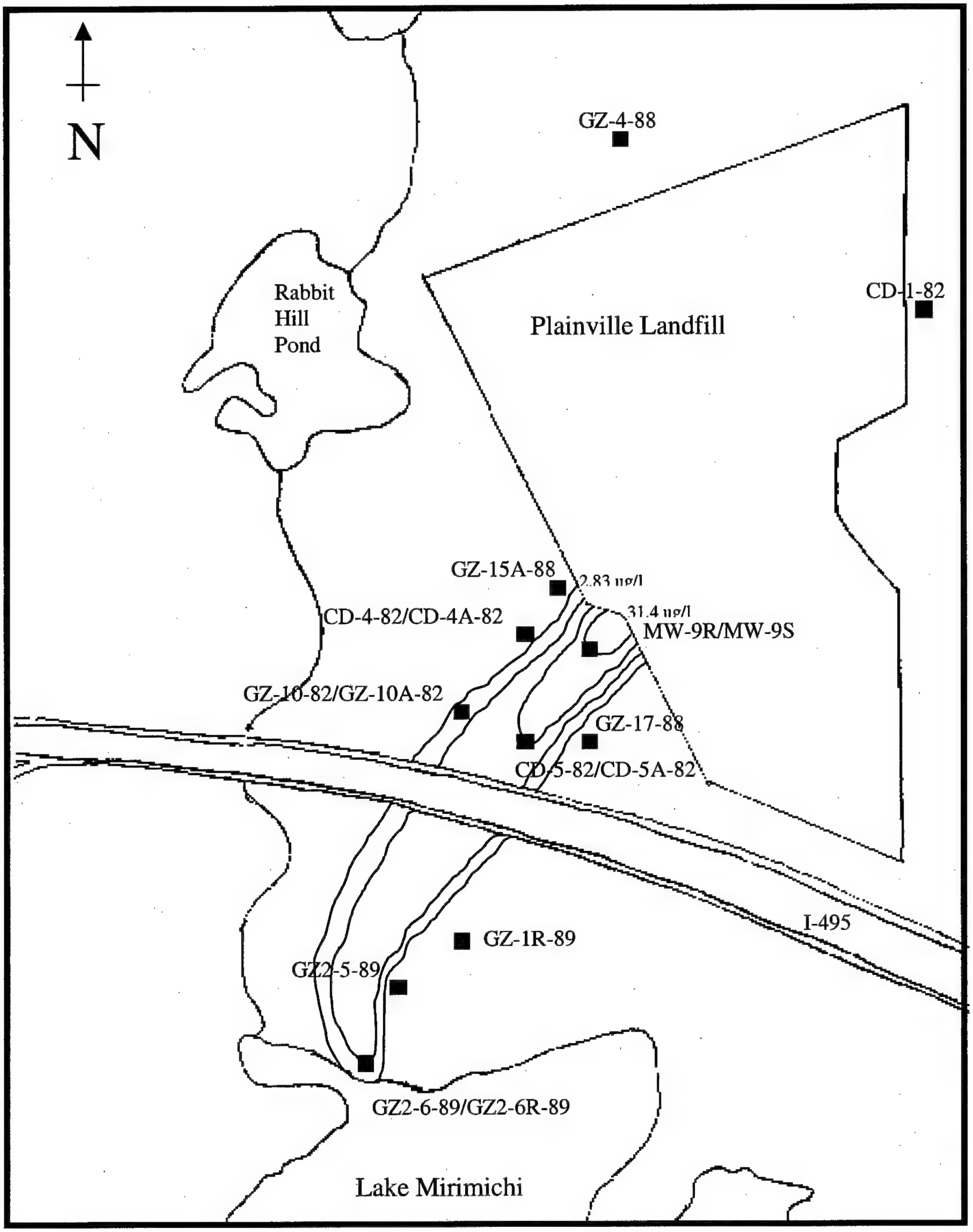

Figure 23 1,4-Dichlorobenzene Plume – Overburden – March 1997

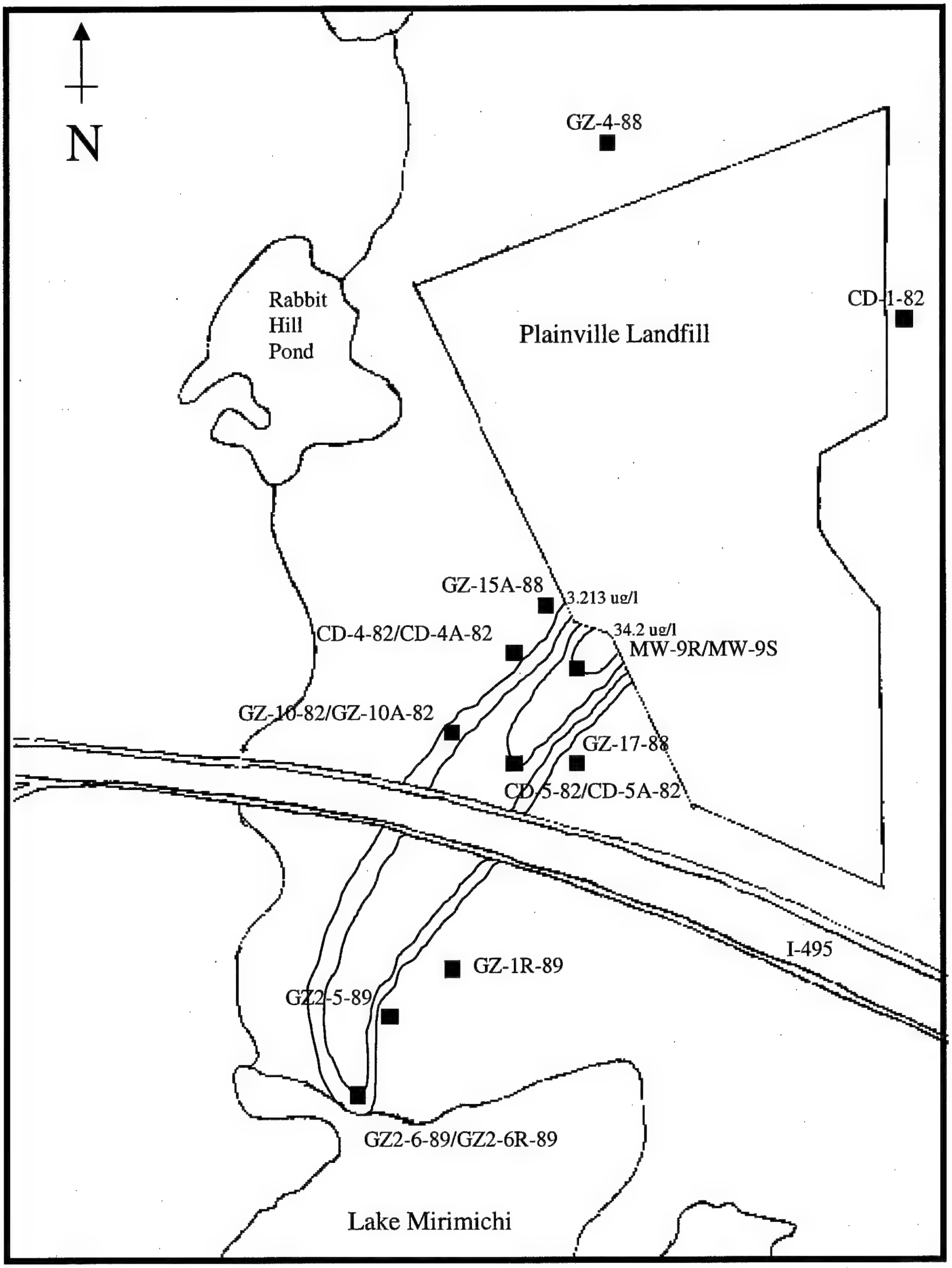

FIGURE 24 1,4-DICHLOROBENZENE PLUME – OVERBURDEN – JUNE 1997

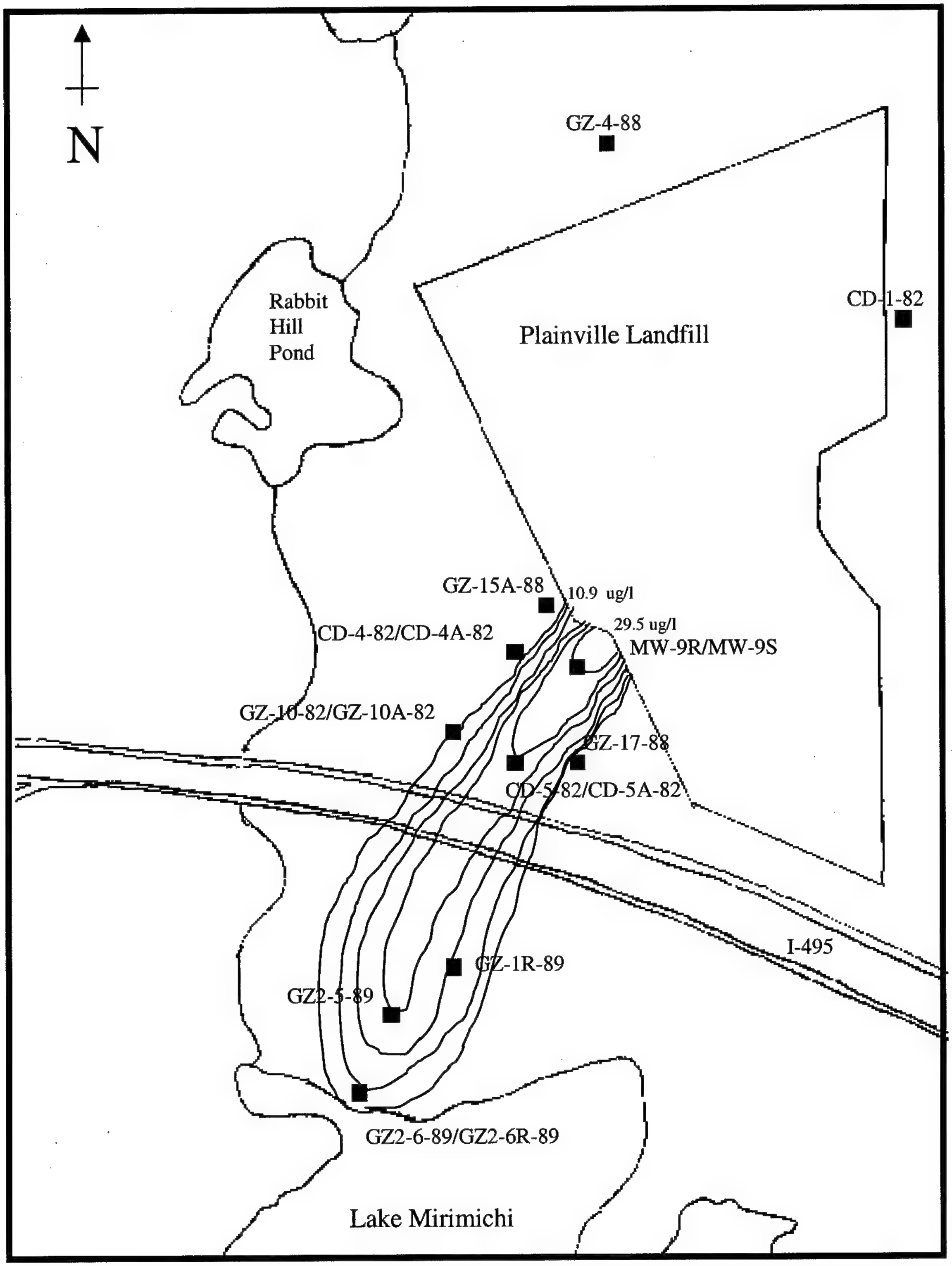

FIGURE 25 1,4-DICHLOROBENZENE PLUME – OVERBURDEN – SEPTEMBER 1997

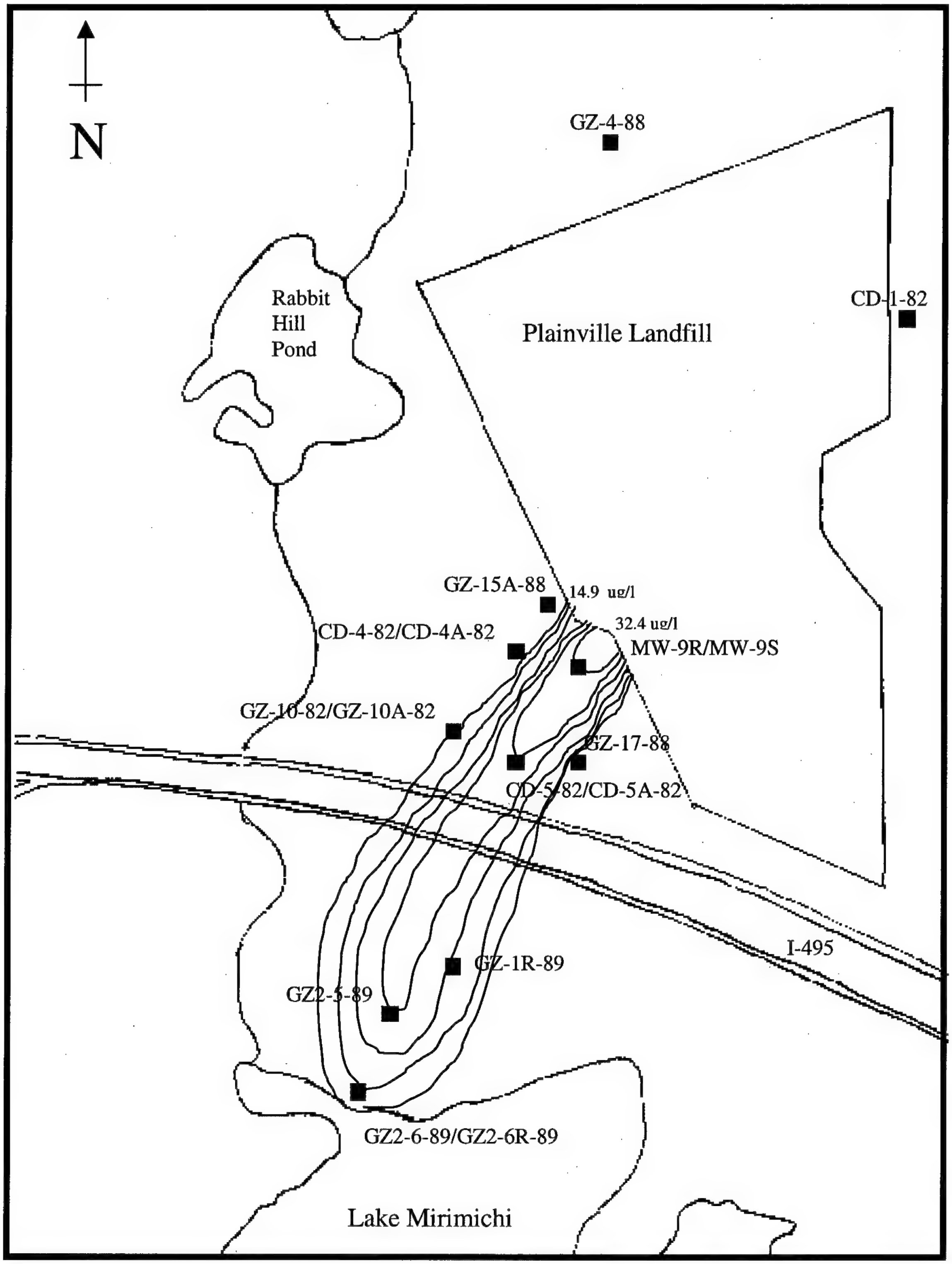

FIGURE 26 1,4-DICHLOROBENZENE PLUME – OVERBURDEN – DECEMBER 1997

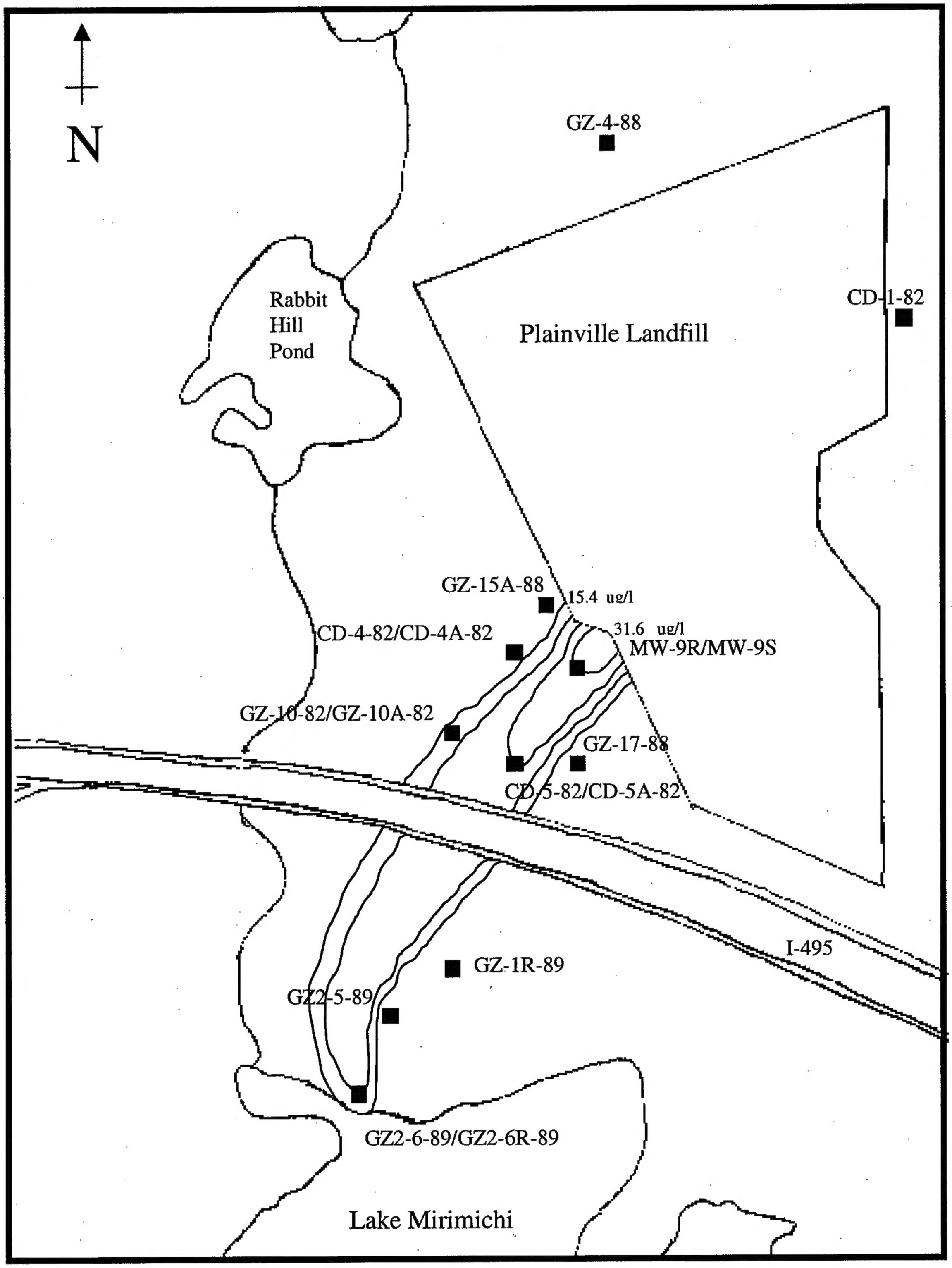

FIGURE 27 1,4-DICHLOROBENZENE PLUME – OVERBURDEN – MARCH 1998

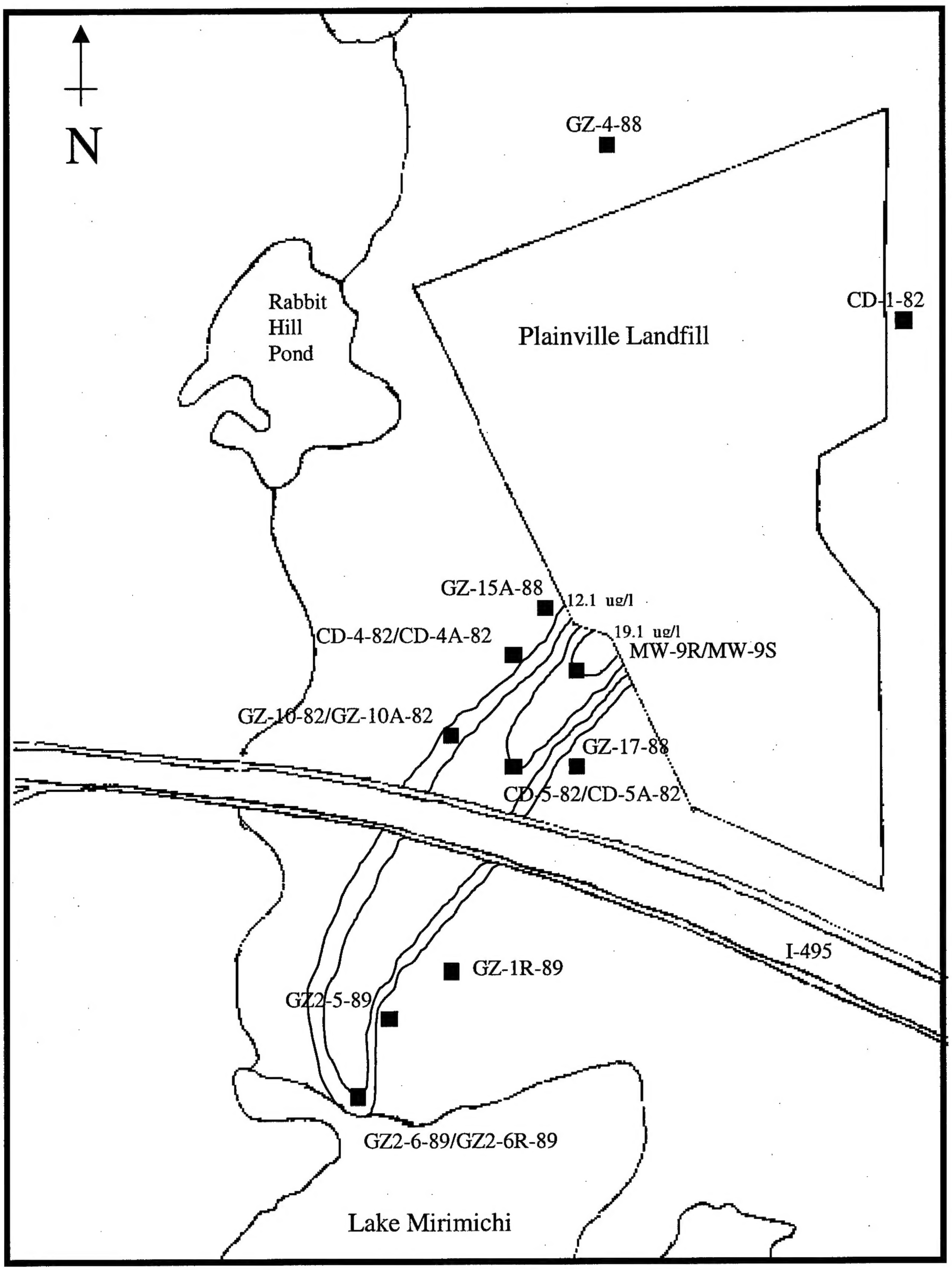

FIGURE 28 1,4-DICHLOROBENZENE PLUME – OVERBURDEN – JUNE 1998

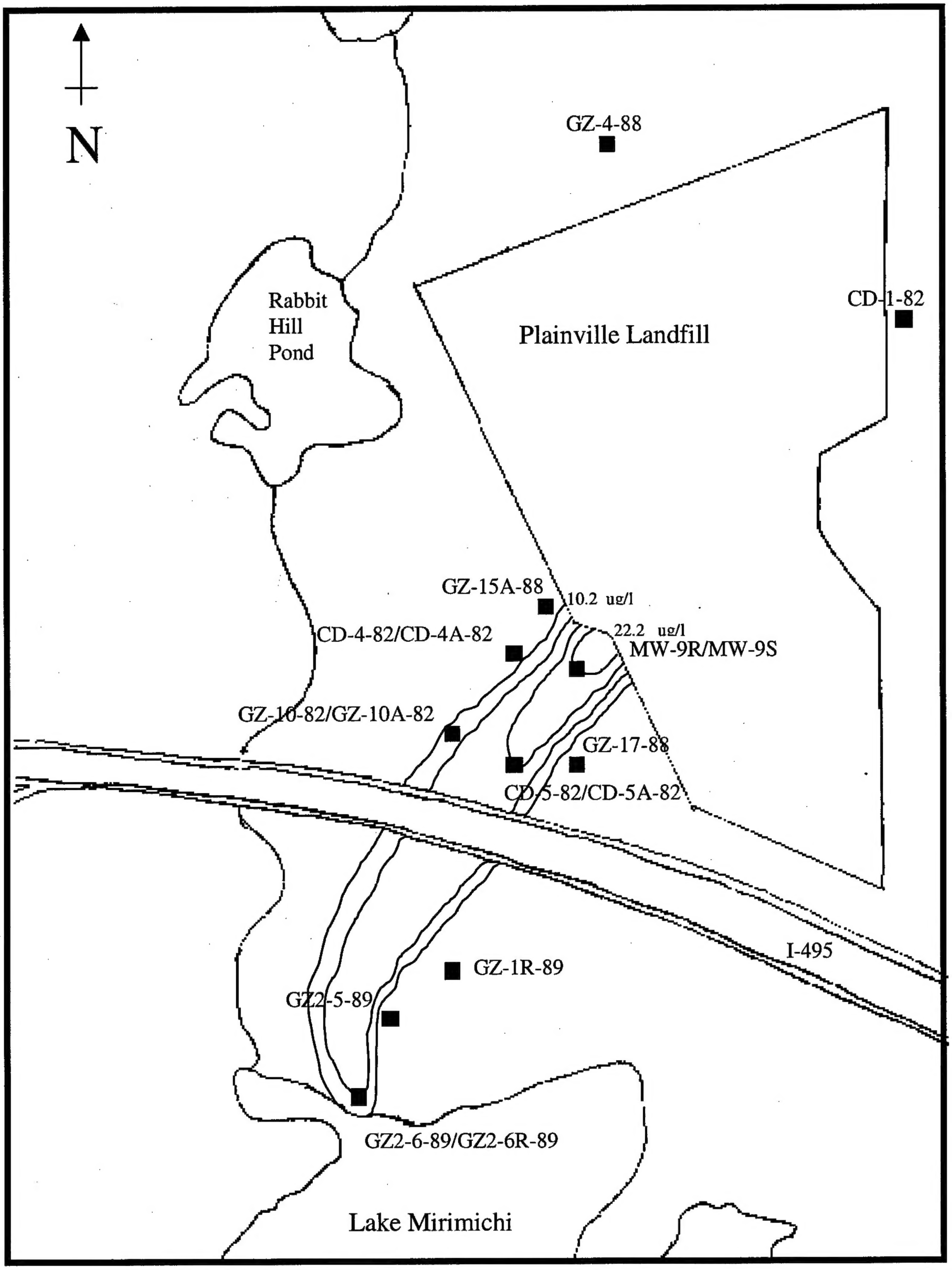

FIGURE 29 1,4-DICHLOROBENZENE PLUME – OVERBURDEN – SEPTEMBER 1998

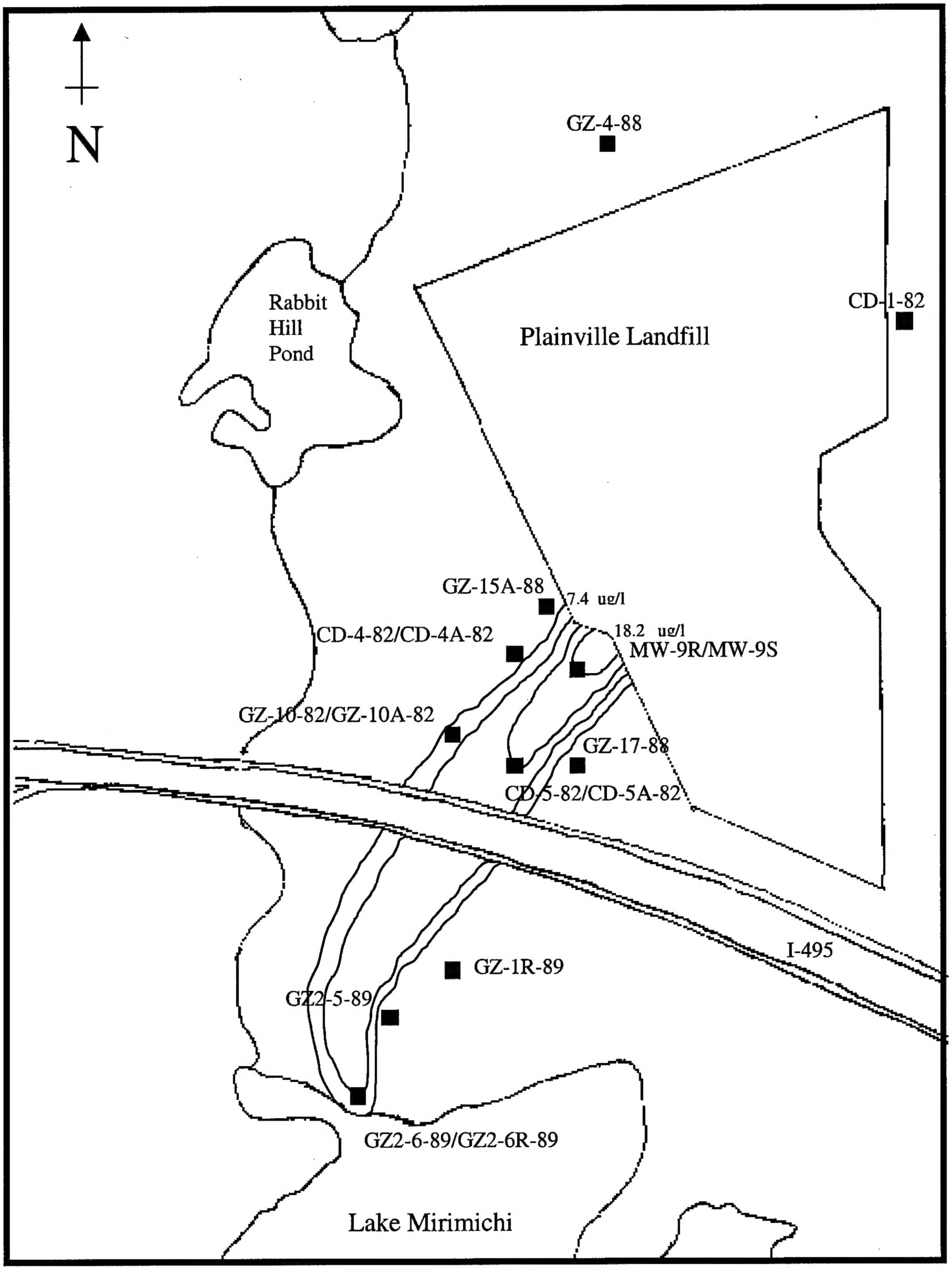

FIGURE 30 1,4-DICHLOROBENZENE PLUME – OVERBURDEN – DECEMBER 1998